JOURNAL
OF THE
AMERICAN WATER WORKS ASSOCIATION

Vol. 38 | **MAY 1946** | **No. 5**

Contents

All correspondence relating to the publication of papers should be addressed to

Harry E. Jordan, Secretary

500 Fifth Avenue, New York 18, N. Y.

$7.00 of a member's dues are applied as subscription to the JOURNAL.

Additional single copies to members—50 cents

Single copies to non-members—75 cents

JOURNAL
OF THE
AMERICAN WATER WORKS ASSOCIATION

Vol. 38 | May 1946 | No. 5

Des Moines Pension and Retirement System

MANY water department executives have either established retirement plans for their personnel or are contemplating the establishment of such plans. Mr. Dale Maffitt, who submitted the document printed below, is General Manager of the Des Moines Water Works and the Chairman of the Association's Committee on Pension and Retirement Plans. Following the enactment of certain laws by the 1945 General Assembly of Iowa, the Des Moines Water Works has set up a "Declaration of Trust" covering a retirement plan and pension system for that water department. Upon the assumption that this carefully drawn document will be of interest to you and other water works executives, it is published herewith. [EDITOR'S NOTE.]

Des Moines Water Works Retirement System

THIS DECLARATION OF TRUST made this 10th day of December, 1945, by the Board of Water Works Trustees of the city of Des Moines, Iowa, hereinafter referred to as the "employer," WITNESSETH:

WHEREAS, the Water Works System of the city of Des Moines, Iowa, is an instrumentality, owned by the city of Des Moines, Iowa, and the employer is by law charged with the management and operation of such system; and,

WHEREAS, it is provided by law and particularly by the provisions of Chapter 178 of the Acts of the Fifty-First General Assembly of Iowa, that the employer may establish a pension and annuity retirement system for the employees of such water works system; and,

WHEREAS, the employer has determined it to be in the public interest and for the best interests of its employees, that such a pension and retirement system be established,

NOW, THEREFORE, the employer does, by this instrument, create and establish a pension and retirement system, to be known and designated as the "Des Moines Water Works Retire-

ment System," which shall be maintained and administered as follows:

ARTICLE I—Definitions

The following words and phrases when used in this retirement system, unless the context clearly indicates otherwise, shall have the following respective meanings:

1. *Employee:* A person in the employment of the employer on or after the effective date, who then has been employed by the employer continuously for one (1) or more years, who receives regular compensation from the employer for personal services, and whose duties require substantially full-time employment.

2. *Service:* The last continuous period of employment as an employee by the employer immediately preceding retirement. A leave of absence granted by the employer for military service or other reasons shall not be considered to break continuity of employment and shall be considered as service, if the employee returns to the employment of the employer on or prior to the expiration of such leave.

3. *Earnings:* The amounts, before deductions, agreed to be paid by the employer to the employee for personal services during the period of service considered hereunder. Earnings for all service prior to the effective date will be assumed to be equal to the average of the earnings during the period of service within the five (5) years immediately preceding such effective date. Earnings of an employee during a leave of absence granted by the employer for military service or other reasons, will be assumed to be the amount which such employee would have received in the continued service of the employer for the period of such leave computed at the rate of compensation received by such employee during the last calendar month preceding such leave.

4. *Annuity:* A series of uniform monthly payments payable to a retired employee, the first such payment to be made as of the beginning of the month following the date of retirement, and the last payment to be made as of the beginning of the month in which the death of the retired employee occurs.

5. *Effective Date:* December 31, 1945.

ARTICLE II—Contributions

Employee Contributions: The employer shall deduct three per cent (3%) of the earnings of each employee, on or after the effective date and such deductions shall constitute the contributions of the employee. The amount of such contributions shall be reduced by the amount of contributions from such earnings to any state or federal pension annuity or retirement system.

Employer Contributions: The employer shall make such contributions as are required, in addition to the contributions of the employees, to meet the costs of maintaining this retirement system. The annual contributions of the employer are to be equal to the normal cost for the year required to provide benefits not provided for by employee contributions, plus the amount necessary to amortize the remaining unfunded past service requirement over the remainder of the twenty-five (25) year period following the effective date.

ARTICLE III—Retirement

The employment of each employee shall be terminated upon attainment of age sixty-five (65) unless the employer shall request such employee to continue

in employment, but in no event shall any employee who has attained the age of seventy (70) be in the employment after Jan. 1, 1949. An employee shall be considered retired and entitled to an annuity upon the happening of any one of the following:

1. If employment is terminated after attainment of age sixty-five (65) and after twenty (20) years of service;
2. If employment is terminated by the employer after attainment of age fifty-five (55) and after twenty (20) years of service;
3. If employment is terminated by the employer for total and permanent disability of the employee after ten (10) years of service; or
4. If employment of employee in Service as of the effective date is terminated after attainment of age sixty-five (65) and after ten (10) years of service.

ARTICLE IV—Retirement Annuities

An employee retired on or after attainment of age sixty-five (65) shall be entitled to an annual annuity equal to the sum of the following:

1. One and one-half per cent ($1\frac{1}{2}\%$) of earnings during each year of service after the effective date; plus
2. One per cent (1%) of earnings during each year of service prior to the effective date, not exceeding twenty-six (26) years, provided such employee continues in service one (1) or more years after the effective date.

Any employee retired prior to age sixty-five (65) shall be entitled to an annuity beginning upon attainment of age sixty-five (65); the amount thereof to be determined as for retirement at age sixty-five (65), but considering only earnings and service prior to actual retirement. Such an employee, or if mentally incompetent, his guardian, under order of Court, may elect to receive an annuity to begin on the day following actual retirement or upon any later date prior to age sixty-five (65), equal to the actuarial equivalent of the annuity otherwise payable.

Any annuity of less than ten and no/100 ($10.00) dollars per quarter, may be paid in a single lump sum actuarial equivalent.

ARTICLE V—Death Benefits

Upon the death of an employee prior to termination of employment, or upon the death of a retired employee prior to receiving annuity payments equal to the sum of all his employee contributions with interest at two (2%) per cent per annum, a death benefit shall be payable. Payment shall be made in a single sum as soon as is practicable after the filing of a claim with the employer by the beneficiary or beneficiaries named to receive such death benefit in the last written instruction filed with the employer by the employee or retired employee, as the case may be. If no beneficiary is so named, such benefits shall be paid to the widow of such employee, and if none, to the estate of such employee. The amount of the death benefit shall be the sum of all the employee contributions with interest at two (2%) per cent per annum less amount of annuity payments, if any, made under the provisions of this retirement system.

ARTICLE VI—Separation Benefits

Any employee, upon termination of employment prior to death or retirement, shall be entitled to a separation benefit equal to the sum of all contributions made by the employee to this retirement system with interest at two (2%) per cent per annum. All rights

of an employee under this retirement system shall cease upon payment of a separation benefit.

ARTICLE VII—Limitation of Benefits

Nothing contained in this Declaration of Trust shall be construed as a contract of employment between the employer and any employee, or as creating a right in any employee to be continued in the employment of the employer or as a limitation on the right of the employer to discharge any employee with or without cause.

ARTICLE VIII—Trust Estate

All contributions, together with the investments thereof and the income thereon, shall be held, invested and used for the exclusive benefit of this retirement system.

ARTICLE IX—Administration of Trust Estate

The trust estate, which shall consist of all contributions, together with investments thereof and the income thereon, shall be administered by the employer. In such administration the employer may use one or more of the following methods:

1. The employer may administer such Trust Estate in whole or in part as trustee, or

2. The employer may contract with any legal reserve insurance company authorized to do business in the state of Iowa and to enter into contracts of the character required, for either individual or group policies, as will, in the employer's judgment, accomplish the purposes of this retirement system, and may use the funds in the trust estate therefor.

In the event the employer shall as trustee administer any or all of the trust estate, the employer shall do so subject to such rules and regulations as the employer from time to time shall adopt, and shall exercise all other rights and powers ordinarily conferred upon trustees administering Trust Estates under the laws of Iowa.

As trustee, the employer shall have power to invest, re-invest, sell and exchange the trust funds, securities and property. In doing so, the employer shall exercise that judgment and care under the circumstances then prevailing which men of prudence, discretion and intelligence exercise in the management of their own affairs, not in regard to speculation but in regard to the permanent investment of their funds, considering the probable income as well as the probable safety of their capital. Within the limitations of the foregoing standard, the trustees shall not be limited to the acquisition and retention of any particular security or property.

Payments from the trust estate may be made for annuities, benefits and costs of administration, but only upon certificate or resolution of the employer, that the same are due and payable.

In the event the employer elects to contract for insurance, either individual policies for the benefit of individual employees, or group policies for the benefit of all or a part of the employees, such contract or contracts of insurance shall provide for payment of the benefits and annuities to the employee or employees insured, as provided in this retirement system, but the insurance company or companies which shall issue the policies shall have no other obligations than those expressed in the policies and shall have no obligation to inquire whether the requirements of

the trust have been met and no obligation as to the application of funds. No insurance company shall be deemed a party to or a beneficiary of the trust.

ARTICLE X—Liabilities of Trustees

All payments of benefits as provided in this trust shall be made solely out of the assets in the trust and the employer shall not be liable for any act or failure to act not amounting to a breach of good faith.

ARTICLE XI—State or Federal Benefits

Nothing in this retirement system shall prevent any employee from receiving benefits from any pension, annuity or retirement system heretofore or hereafter adopted by the state or federal government, but in the event the employees become covered by any such system, the retirement benefits provided for them thereafter under this retirement system shall be reduced by the amount of the benefits provided for them, exclusive of widow and dependent benefits, under any such system, or by an amount actuarially equivalent to such benefits.

The employer may, but shall not be required to, take such action as in the exercise of its sole discretion it may determine necessary to secure the benefits of any such state or federal system for the employees or their dependents.

ARTICLE XII—Amendment

The employer may amend this Declaration from time to time and in all respects provided only that no such amendment shall permit any part of the Trust Estate to be used for or diverted to any other purpose than for the exclusive benefit of this Retirement System.

ARTICLE XIII—Termination

The employer reserves the right to terminate this retirement system at any time. In the event the trust estate is being administered by the employer as trustee, then upon such termination the assets are to be liquidated by distributing to each employee or retired employee an amount equal to the death benefit which would have been payable if death occurred on the date of termination plus such additional amount as can be provided by the remaining assets to make the total payable to each employee or retired employee in proportion to the actuarial equivalent of the annuity payable upon retirement at age sixty-five (65) based on earnings and service to the date of termination.

In the event the annuities and benefits for any employee or retired employee are insured under a contract of insurance, upon termination each employee shall be entitled to receive the paid up benefits purchased for him prior to such termination by both his contributions and those of the employer in his behalf.

ARTICLE XIV—Miscellaneous Provisions

1. *Construction:* In the event a dispute shall arise over the proper construction to be given the meaning of any part of this declaration the decision of the employer shall be final and binding upon all parties.

2. *Assignments:* Annuities and benefits provided in this retirement system shall not be subject to assignment, pledge, sale, garnishment or attachment, and any such assignment, pledge, sale, garnishment or attachment shall be null and void, and the employer as trustee and any insurance company or companies which may insure payment

of any such annuities and benefits, shall not be required to recognize any such assignment, pledge, sale, garnishment or attachment.

3. *Rules and Regulations:* The employer may from time to time adopt rules and regulations for the proper administration of this retirement system.

4. *Records:* The employer shall maintain a separate set of records for this retirement system which shall include contribution accounts, minutes of meetings, and such other pertinent records as the employer may determine necessary.

DES MOINES WATER WORKS BOARD OF WATER WORKS TRUSTEES

By ....
Chairman

ATTEST:

....
Secretary

Utility Representatives in Washington

Utility managers with civilian construction problems are referred to Mr. Paul Valle, Administrator of Utilities in the Civilian Production Administration. Mr. Valle acts as the clearing agent for information and services to the extent that they are now organized in Washington to give such aid. He may be reached at Social Security Bldg., Room 4653, Washington, D.C.; or by telephoning Republic 7500, Ext. 71716.

Nelson Wyatt, Housing Chief, in a projected departmentalization of the Housing Administration, has named Mr. Frank Herring as contact man with municipal agencies. Although the housing program proposed by Wyatt still awaits congressional approval, it may be safely assumed that some such plan will be under way very shortly.

Development of Water Supplies for Military Projects

By Rufus W. Putnam

Dist. Engr., U.S. Engineer Dist., Los Angeles, Calif.

Presented on Oct. 25, 1944, at the California Section Meeting, Los Angeles, Calif.

THE construction of military projects for training, mobilization and war has been a function of the Corps of Engineers, U.S. Army, since the enactment of National Defense legislation in 1940. The initial assignment, commencing in December 1940, was limited to the planning and building of military airports and coastal fortifications. About a year later the assignment was greatly extended to include all construction for the Army in the United States and possessions. The magnitude of the work conceived and completed during the past four years at home is one of the many outstanding accomplishments of the Corps of Engineers in its notable history.

The Corps of Engineers during peacetime or war is under the direction of the Chief of Engineers and his office, and functions through the United States Engineer Department. The country is divided into nine divisions, according to the boundaries of nine military service commands, with two additional divisions in the Mississippi Valley which have only civil works to perform. Each division is further subdivided into several districts. Each division and district office of the U.S. Engineer Department is directed by an officer of the Corps of Engineers and his staff. The civilian employees of the department are appointed by the Civil Service Commission as requested by the District Engineer.

Following the passage of congressional acts providing funds for national defense, the United States Engineer offices were reorganized, practically overnight, into specialist units for planning, designing and constructing a myriad of military facilities. The department was greatly expanded and no doubt city, county and state engineering departments felt the pinch of loss in manpower due to specialists and others leaving for the federal service.

The already immense program of defense construction was greatly expanded following Pearl Harbor. This expansion, occurring almost simultaneously with men leaving for the service, depleted the ranks of the U.S. Engineer Offices. Replacements with qualified personnel became more and more difficult. It became advisable to employ the services of established architect and engineer organizations to assist in the preparation of plans. Much of the work was done by such organizations under the supervision of District Engineer offices. All construction was performed by private contracting firms who, with the manufacturers of materials and equipment, were directly charged with actual completion of projects within specified time limits.

Volumes could be written, and probably will be, describing in detail the various phases of the war effort, each in themselves an immense undertaking and collectively approaching a magnitude bordering on the fantastic. It will suffice to state here, however, that every project, regardless of size, location or nature of activities, required an immediate water supply for construction purposes, followed as soon as possible by a more elaborate water works system to allow early activation by troops. The development of a supply of water is thus the number one problem for the military engineer, whether it be for a training camp at home or for troops in combat overseas.

The selection of sites for military projects can seldom give prime consideration to the availability of an adequate supply of water. This was particularly true in the recent war which required the training of the greatly expanded air force in flying, aerial gunnery and bombing. For this combat arm, as for mechanized units, anti-aircraft and long-range artillery, it was desirable to have a wide expanse of sparsely inhabited and untilled land. Obviously such areas, while providing strategic or tactical requirements, rarely have an existing or easily accessible source of water supply. A site having every advantage except the necessary water will be selected if water is known to be anywhere within a reasonable distance. The plan in such instances proposes prospecting for water at or very near the site; if unsuccessful, a more remote source must be utilized. During the mobilization period only occasionally were sites selected which required installation of pipelines to carry water from a source more than 5 miles away. After Pearl Harbor the need for additional sites having tactical or training advantages required locating projects farther and farther away from known sources of water. Pipeline exceeding 10 miles in length were not uncommon and in several localities favorable to specialized training it was necessary to pipe water over 25 miles.

Prior to 1942, the boundaries of the Los Angeles U.S. Engineer District included the Great Basin, the Colorado River basin and minor drainage areas west of the continental divide, and the coastal basin in California south of Cape San Martin and of the southerly limit of the San Joaquin valley. All of Utah and Arizona, southeastern Nevada, southern California and portions of Wyoming, Idaho, Colorado and New Mexico were within this dictrict. The same boundaries were retained for war construction for about the first year but were changed early in 1942 to conform with the eastern boundary of the Ninth Service Command. Newly organized districts removed for military construction certain portions, leaving southern California, southern Nevada and all of Arizona in the Los Angeles District.

Within the present district boundaries are included most of the desert and semi-arid regions of the Southwest, which have afforded more advantageous training sites for both air and ground forces than most localities elsewhere in the United States. Climatic and atmospheric conditions are favorably suited to all phases of air forces training. The desert areas also have provided training and maneuver grounds for troops simulating warfare in the African deserts. Thousands of square miles of vacant land were available for anti-aircraft, artillery, mobile units and for aerial gunnery and bombing. It is not surprising then that the District Engineer Office in Los Angeles

was assigned a volume of military construction which represented an expenditure of about $600,000,000.

The difficulties attending development of water supplies for these numerous projects were as pronounced as those confronting military engineers anywhere on the home front. The lack of water in the district is evidenced by the fact that three of the world's great aqueducts traverse the area to carry water from the Sierra Nevada Mountains and Colorado River to Los Angeles and other cities and to irrigation projects and agriculture. Also, scattered throughout the district, are dams and reservoirs impounding runoff from rainfall in the wet season for use during months having little or no precipitation. The existence of aqueducts, canals and reservoirs made possible in a great measure the selection of training sites which would otherwise have required huge expenditures of funds for long pipelines and pumping plants. None of these major water supply systems existing previous to the inauguration of the defense and war work was being drawn upon for delivery of water at rates anywhere near capacity, so they could be utilized to the fullest extent as sources for Army water supply systems. Connections to existing systems were given preference as a means of expediting water supply development and minimizing the need for locating and developing new supplies.

Some conception of the extent of water supply development in the Los Angeles District is derived from a brief summary of the work accomplished. In the four-year period from 1941–1944, 190 projects requiring water supply systems were completed. Of these, 125 obtained their main supply of water from existing sources, while the development of new sources was required in 65 cases. Of the newly developed sources 55 were from deep wells and 10 from surface waters. One hundred fifty deep wells were drilled. The combined capacity of the supplies developed from new sources was in excess of 75 mgd. The water works systems constructed for all projects had a total capacity capable of supplying the daily needs of over 800,000 troops.

Selection of Site

The selection of a source for development of a water supply for a military project takes into consideration availability, quality and adequacy. Cost is considered unless the location of the project must be determined on the basis of military requirements. The supply which can be developed at the lowest first cost is preferred for temporary or semi-permanent military installations. Planning a water supply for permanent posts includes economic studies similar to those employed in normal civil projects. The same standards of quality are maintained as those specified by the U. S. Public Health Service for drinking water. The water must be safe bacteriologically—free from pathogenic bacteria, parasitic protozoa or visible impurities. The water should also be attractive in taste and color and palatable to the extent that troops will unhesitatingly use such quantities as are necessary to maintain their health and comfort. After health standards have been met, it is desirable to provide water having a chemical constituency that will not corrode or cause clogging of plumbing fixtures, equipment or apparatus. Obviously all of the desirable qualities cannot be obtained in all water supplies developed either at home or overseas. Safety is the principal consideration in waters of inferior quality. In combat zones additional

safeguards against reinfection or willful contamination by the enemy must be employed.

Modern purification plants were constructed at many of the airfields and cantonments to condition water of inferior quality. Plants for removal of iron were provided where the content exceeded 3 ppm. A softening plant with sufficient capacity to treat the entire water supply of a post was usually installed where the total hardness exceeded 400 ppm. Individual industrial type softeners were installed on services to laundries when the total hardness exceeded 43 ppm. and on other services requiring reduction in hardness when the total exceeded 150 ppm. All water, whether from wells or surface supplies, was sterilized with chlorine in sufficient quantities to maintain a residual of free chlorine of not less than 0.4 ppm. Portable purification and sterilization apparatus were used by troops in the field or in combat zones. Distillation units for brackish water came into wide use. Reports from engineers overseas reveal remarkable performances from water conditioning units under trying circumstances.

The sites for military projects were selected by boards of officers appointed for that purpose and an engineer officer was usually a member of the board. Every conceivable aspect affecting the selection for the purpose intended was considered. Tactical requirements were studied and approval was given the location from that point of view before progressing to other considerations, such as construction difficulties, climatic conditions, transportation facilities, availability of water and power and streams for receiving sanitary sewage. Several alternate locations were investigated and graded according to advantages and disadvantages before the final selection. More often than not water was the only requirement unfavorable to an otherwise ideal location. The engineer officer in such instances made a rapid survey and study of cost and probable difficulties involved in developing a water supply either on the site or some miles away. His report was necessarily concise and assumptions accurate in order to avoid disapproval of a site for which water actually could have been developed economically, or approving an expensive installation where the water supply was liable to fail.

Use of Manual and Standards

Realizing that site board officers and designing engineers would be faced with recurring engineering problems for various projects, the Office, Chief of Engineers, compiled and issued the Engineering Manual in March 1942. This manual standardizes requirements and planning and design criteria for the entire field of military engineering. Water supply requirements are based on standards of the American Water Works Association and the particular military needs of the project according to one of several classifications. The daily per capita allowance ranges from 50 gal. in a field camp to 150 gal. at a permanent post or hospital. Theater of operation or temporary type construction provides 70 gal. per person and a semi-permanent project is allowed 100 gal. The requirements for all types and classifications of Army projects are tabulated for ready reference in the engineering manual (see Table 1).

The initial development and construction of a water supply system is based on the authorized population increased by a capacity factor varying

TABLE 1

Per Capita Water Allowances for Army Projects

Type of Project	Permanent Posts	Mobilization Type Construction	Theater of Operations Construction	Field Training Camps
Airfields, Camps and Cantonments	150	100	70	50
Hospital Units (including hotels and similar facilities converted to hospital use)	150	150	125	100
Armored Divisions	150	150	100	75
Prisoner of War and Internment Camps			70	50
Hotels and Similar Facilities Converted for Troop Housing	70 gal. per capita			
Plant, Port and Storage Projects (including civilian war workers)	30 gal. per employee per 8-hour shift and 100 gal. for resident personnel			
Animals	25 gal. per day			

Note: The allowances set forth above include water used for laundries to serve the resident personnel, washing vehicles, limited watering of planted and grassed areas and similar uses. Special allowance will be made for operation of hydraulically operated gasoline fueling systems under certain conditions.

from two for populations of 10,000 or less to one for populations of or in excess of 50,000. The capacity factor is applied by multiplying the authorized population by the proper capacity factor, the result being termed the "design strength" or population. The per capita water consumption allowance is applied to the design strength. For example, a temporary project allotted an authorized strength of 20,000 has a design population of 30,000 by applying the 1.5 capacity factor, and requires 2,100,000 gal. for an average day's use at 70 gal. per capita.

The source of water and the development must be sufficient to yield the daily water demand in approximately 16 operating hours if from wells or other pumped supplies.

Having determined the amount of water required, by reference to and application of engineering manual standards, the subsequent and not so simple problem is where and how to obtain it. If the site is adjacent to a city, a canal or an aqueduct, the problem is relatively simplified to the extent that the capacity of the existing system need only be investigated to determine its adequacy to serve the project as well as to meet the increased demand by reason of the Army construction. An average of one out of three projects, however, has been located remote from any known or existing supply, so that new sources had to be located and their adequacy determined before construction could be authorized.

Springs may exist in the vicinity of a proposed project and their history is obtained either from natives or official records. If the flow from springs is determined to be intermittent or seasonal, impounding reservoirs must be designed and constructed to carry over during the off season. Surface supplies from streams are subject to similar studies and hydrologic investigations. One large project in Utah, which require about 1 mgd., is supplied from mountain springs 32 miles away through a gravity pipeline. Another project in Arizona, which is supplied from seasonal springs on the reservation, required construction of impounding reservoirs of over 30-mil.gal. capacity. By far the greatest number of new water supplies developed by the Army are those obtained from drilled wells equipped with deep well turbine pumps.

Basically the methods of developing a water supply for military purposes

do not differ from those employed by engineers or geologists to locate and develop a water supply for a city, industry or agricultural project. There is so little time available, however, for explorations for water to supply a vital training or war project that, unless definite information has already been compiled on possible sources by the U.S. Geological Survey or other agency, some risk must be taken in acting on rather hasty explorations and meager information. The number of wells which have been drilled in desert country for which no logs or other records have been kept is surprising. Valuable test pumping data, whether recorded or not at the time of developing wells, are seldom available for reference. The fact that an area is spotted with wells which have been in operation for a considerable period does not always minimize the difficulties attending explorations for wells required to yield a stipulated quantity. The development of a well supply also includes ascertaining the effect, if any, of additional withdrawals from the basin on established water users. Regardless of how important the military project may be, the government is reluctant to induce inconveniences or hardships of even temporary duration on a locality, if avoidable by employing other means to accomplish the same result.

Army Water Supply Project in Arizona

One of the many deep well supplies developed in the Los Angeles District is selected for a brief review because it incorporated practically all of the usual methods of investigations for water supply, including geology, hydrology, aerial photography, reconnaissance, geophysics and exploratory drilling. Due to the importance of the project and the length of time allotted for investigating and developing a source, the U.S.G.S. offices in Washington and Tucson, Ariz., were called upon to collaborate with the Corps of Engineers.

The project in question is an Army Airfield at Kingman, Ariz., which was built in the early part of the war and which required expansion far beyond the capacity of the existing water supply system. Further development of the original source was determined by geologists to be impossible without seriously affecting the supply to the town of Kingman, which was taking water from the same source. The development of an entirely new supply was necessary. A hasty reconnaissance was conducted by airplane covering a radius of about 40 miles around the airfield and at points on the ground selected from air photos and geologic studies. A location for explorations was decided upon in Hackberry, Ariz., about 25 miles from the airfield, draining an area of about 350 square miles. A limited water development had been carried on in the area by a few ranchers and by a railroad company.

Rainfall records for a period of only 4 years were available for the locality. These showed an average precipitation of about 11 in. Near the upper end of the wash, erosion had progressed to bedrock and the surface flow at that point could be measured and was understood to be perennial. From the personal observation and estimates of a rancher the flow at that point never had fallen below about 350 gpm. in 25 years and during wet cycles probably discharged at two or three times that rate. The normal flow through the wash was subsurface except at the aforementioned point and at a few other locations where impervious barriers brought part of the flow to the

surface. There were available no official runoff records for the area. Several shallow wells were strung along the upper reaches of the wash and were being used intermittently for irrigation. No records of any kind were available for those wells. The discharges of the better wells were estimated at 500 gpm. None of the wells had ever been pumped for long or continuous periods. Farther down the wash, a railroad company had drilled four wells and cut galleries to intercept subsurface flows. The average combined use from those wells was about 300 gpm. About 4 miles below the railroad wells the wash fanned out and lost its identity on the desert. Briefly, this was the situation regarding water when explorations were started.

The possibilities of developing 2,100 gpm. in such an area seemed rather remote; however, this is one instance where the problem of developing a supply for a comparatively short-lived military project has the advantage over a development for the ever increasing demand of a city or the perpetual demand of agriculture. Water stored over a period of years in a basin at low recharge rates is available for withdrawal at rates exceeding the rate of replenishment by a project of temporary duration; therefore, a source of this nature can be considered for a military project if the storage basin is extensive enough to provide the quantity of water needed for a definite period. A geologic survey to determine the areal extent of this particular basin was therefore the initial phase of the investigation.

An aerial survey covering an area of approximately 600 square miles was made to assist in the geologic work as well as to ascertain all other possible sources for water and finally to select routes for pipelines. The area was photographed with an 8¼-in. lens aerial camera making possible the use of the normal multiplex aero projector to construct a topographic map at a scale of 1 : 12000 with 20-ft. contours. The area was flown at an altitude of approximately 13,650 ft. above the ground elevation and required 180 exposures with the regular 60 per cent and 40 per cent overlap for stereoscopic coverage. A partially controlled mosaic was made with slotted template control utilizing a limited amount of available ground control. This mosaic was taken in the field to assist in the reconnaissance and further geologic mapping. In collaboration with the Los Angeles District Engineer's Office, the geologic studies for this development were conducted by Samuel F. Turner of the U.S.G.S. Office in Tucson, Ariz.

The general geology was correlated with probes to bedrock across the length and breadth of the basin. The probes to bedrock with electrical geophysical methods, using the Gish-Rooney type of apparatus, were done by H. C. Spicer of the U.S.G.S. Office in Washington, D.C. The instruments used for this particular investigation were limited to probes 1,000 ft. in depth. Each probe was logged similarly to a well driller's log and, although water cannot be reliably located by this method, formations which under proper conditions would carry water can be determined. The bedrock contours were plotted from the results of this geophysical work and certain probes were selected as locations for drilling test wells on the basis of the extent of possible water-bearing strata indicated by the resistivity log.

The test wells, 6 in. in diameter, were drilled by the well drilling section of the 515th Engineer Water Service

Battalion under command of Capt. V. C. Michal, Corps of Engineers, using an Army rotary rig. Samples of material were taken at frequent intervals and cores were taken of important water-bearing strata. A well drilling contractor was also engaged to drill a 16-in. well using a percussion type rig and the California Stovepipe method. The site for this large well, intended for one of the permanent operating wells if successful, was selected at the most likely location on the basis of preliminary explorations. Samples of materials were also taken from this well during drilling operations.

Classification of all materials from wells and computations of permeability of water-bearing strata were made in the U.S.G.S. laboratory in Tucson. The 16-in. well was test pumped after being drilled to a depth of 740 ft. to obtain the drawdown and specific capacity. A second 16-in. well was drilled at a location in the upper portion of the wash at a location selected from an analysis of a geophysical probe and a 6-in. test well. All technical data and results of drilling were assembled and analyzed by the District Engineer Office in Los Angeles. It was concluded and recommended to the Chief of Engineers that the area would yield the required amount of water for the duration of the project.

Subsequently, four additional wells were drilled and a 25-mile pipeline constructed to the airfield water distribution system. Each well was equipped with a deep well turbine pump. The three deepest wells were equipped with submersible electric-motor-driven pumps, each of 300 to 350-gpm. capacity. A diesel electric generator plant was constructed in this well field to furnish power for the three 85-hp. submerged motors. The upper wells, having a combined capacity of about 1,200 gpm., were equipped with gasoline-engine-driven deep well turbine pumps. Also, included in this water supply development was a 500,000-gal. concrete reservoir, two 100,000-gal. storage tanks and a chlorinating and metering station.

All exploratory work and the final design and construction of the extensive system was completed in a few months. The entire system cost about \$600,000. It made possible the continuance and expansion of specialized training at one of the airfields particularly vital to the war effort. The only alternative to developing water from this source was the construction of a 38-mile pipeline to the Colorado River with five or six pump stations to lift the water a total of about 3,800 ft., and installation of a treatment plant and reservoirs at a total cost of more than \$2,500,000.

Other Projects

The methods used in developing other well supplies, while not nearly as extensive as the one reviewed above, followed a somewhat similar routine. Where some doubt was entertained as to the probable quality of the water to be produced, chemical analyses were carried on during the well drilling operations. Samples were taken of water from each new water-bearing strata, and perforations were cut in the casing opposite only those strata indicating the better quality water. In one well the total hardness varied from 450 to 1,400 ppm. If the points for perforating had not been selected, the total hardness of the water developed would have been in excess of 900 ppm. Actually the water finally developed had a total hardness of about 480 ppm. Similar methods were used in wells

near the coast where hydrogen sulfide was more predominant in some strata than others.

A complete chemical analysis and a bacteriological examination were made on water taken from every well drilled by the U.S. Engineer Office. Accurate logs and classification of material, location of perforations and results of test pumping were also recorded. Every well was sterilized with a chlorine solution before being placed in operation, regardless of the result of the bacteriological examination. Wells in the Los Angeles District were drilled to depths ranging from 80 to 940 ft. and produced quantities up to 2,000 gpm. The deepest static water level encountered was 690 ft. below the surface. The water from this well, drilled in a porous lava formation in southern Arizona has a temperature of about 106°F. The chemical analyses of several desert wells show a fluorine content in excess of the 1 ppm. allowed by the U.S.P.H.S. Standards. Some wells in the Mojave Desert had fluorine content as high as 10 ppm.

Army Water Distribution

The distribution of water in a military project in general is similar in every respect to the distribution gridiron for a municipal system. Pipelines are laid along street lines, gate valves are provided at selected points, fire hydrants are placed at street intersections or spaced according to the hazard in the area served; building services are connected to main pipelines with standard fittings and outside shut-off valves provided. Cross-connections with pipelines or appurtenances not carrying potable water are not allowed under any circumstance. Where the topography permits, the static pressures are maintained between 40 and 60 psi. and in no instance less than 40 psi. Where static pressures exceed 100 psi., reducing valves and zoning are resorted to.

The distribution system is designed to meet required fire flow demands and instantaneous peak flow rates. The fire flow rates, as tabulated in the Engineering Manual (Table 2), are based on a modification of Fire Underwriters requirements for municipal water works practice. The instantaneous peak domestic rate is computed at two and one-half times the average daily consumption rate. Where fire engine pumpers are used the distribution system is designed to meet the required fire flow demand, that is, the fire flow rate plus 50 per cent of the average daily rate, with a residual pressure of 10 psi. In small camps, where fire pumpers are not used and where fire fighting is accomplished by direct fire hydrant streams, the residual pressure maintained is 35 psi. The Hardy-Cross method of analyzing pipe networks is utilized in the design of distribution systems.

The coefficient of friction used most generally in pipeline design is $C = 100$ in the Hazen-Williams formula or $N = .013$ in the Manning formula. Government regulations for use and conservation of critical materials are rigidly adhered to in the development and design of an Army water supply system. These regulations, as well as delivery dates of materials, dictated to a great extent the type and kind of material or equipment specified. Pipelines for temporary projects were designed on the basis of a useful life of 10 years. Actually it was necessary to make use of about every kind of material or equipment during the more critical period of material shortage. Substitute materials were used wherever possible, although in water works practice the greatest

TABLE 2

Fire Flow Requirements for Army Projects
(*Note: 1–2 = 1 fire for 2 hours; 1–4 = 1 fire for 4 hours, etc.*)

Type of Project	Fire Flow—*gpm.*						
	150 to 250	500	750	1,000	1,500	2,000	4,000
I. Airfields, Camps and Cantonments							
(a) Mobilization Construction							
1. Less than 6,000 but more than 1,000 population				1–2			
Warehouse Area				1–4			
2. 6,000 or more population				2–4			
Warehouse Area						1–4	
(b) Theater of Operations Construction							
1. Less than 6,000 but more than 1,000 population			1–2				
Warehouse Area			1–3				
2. 6,000 or more population			2–3				
Warehouse Area					1–3		
(c) Dispersed Layouts		1–2					
(d) Small Camps and Cantonments Less Than 1,000							
1. Less than 300 population	Fire flow incidental to domestic flow						
2. 300 to 499 population	1–2						
3. 500 to 1,000		1–2					
(e) Station Hospitals							
1. Below 250 beds				1–2			
2. 250 to 499 beds				1–3			
3. 500 to 999 beds					1–3		
4. 1,000 or more beds						1–4	
II. General Hospitals						1–4	
III. Port and Storage Projects							
1. Less than 1,000,000 sq.ft.						1–4	
2. 1,000,000 or more sq.ft.							1–4
IV. Tent or Hutment Camps*							
V. Plants†							

* For tent or hutment type camps it is necessary to provide fire protection only for warehouses, mess halls, latrines and similar structures. Fire protection for these structures will be in accordance with the requirements set forth above for Theater of Operations Construction, unless a dispersed layout is used. If a dispersed layout is used the fire protection will be as set forth above for Dispersed Layouts.

† As determined for individual projects.

portion of material and equipment cannot be substituted. A pump, valve or fire hydrant must be made of metal of weights capable of withstanding work loads and resisting wear.

The water supply, distribution and service piping in Army water works systems were all sterilized with chlorine before being placed into operation, as were wells, storage reservoirs and tanks. A dosage of 50 ppm. was applied to pipelines and tanks and 150 ppm. in wells. A minimum contact period of from 6 to 8 hours was provided during which time gate valves and fire hydrants were operated to

bring the solution in contact with these accessories. After sterilization the mains were thoroughly flushed and samples were taken at several points for bacteriological examination. Sterilization was repeated if the presence of coliform organisms was indicated by the tests.

Storage in Army water systems is provided by elevated tanks, ground tanks or reservoirs. Sufficient capacity is provided to meet 50 per cent of an average day's demand or for the fire demand, whichever is greater. It is planned to have at least one quarter of a day's supply in elevated storage tanks. Storage is augmented also by the fact that 50 per cent of all pumping equipment is equipped with standby gasoline engine power. All fire pumps are gasoline engine driven.

The development, purification and transportation of water overseas is a function of the engineer water supply battalion assigned to an Army. General engineer units if present in the combat unit may be charged with developing water sources and establishing and operating water supply points. A water supply battalion consists of about 500 officers and men and equipment consisting of fifteen water transportation units, six 750-gal. tank trucks and nine purification trucks. In addition to the storage available in the tank trucks, the battalion has eighteen 3,000-gal. capacity canvas tanks and six 260-gal. capacity canvas basins.

The purification unit is a truck-mounted filter plant with a capacity of about 90 gpm. Ammonium aluminum sulfate is utilized for coagulation, sodium carbonate for pH control and sterilization is effected by liquid chlorine. For smaller and isolated groups, a portable purification unit, using hypochlorites for sterilization and having a capacity of 15 gpm., is used. The chlorine dosage is regulated so that the water distributed to troops contains approximately 1 ppm. of residual chlorine. Water is pumped by self-priming gasoline-engine-driven-centrifugal pumps. The equipment normally included with a water supply battalion is capable of pumping 1,890 gpm.; 630 gpm. can be purified. Storage space is provided for 123,000 gal. and transportation is available for 67,500 gal.

Portable distillation apparatus is supplied to troops, especially such organizations as first waves of troops landing on beachheads. These distillation units are of several standard sizes from 50- to 250-gph. capacity. The units are self-contained and consist of single-effect and double-effect evaporators, a pump, an oil-fired boiler, and evaporator and condenser. This apparatus is cumbersome and is used only where other sources of water are entirely unavailable. It was used often in South Pacific campaigns.

The development of water supplies for combat troops or troops stationed overseas is, of course, dictated by local conditions. Any one or all of the usual methods used at home may be employed. The campaign or battle may be lost for want of water at the proper time. The need for water may be more urgent than food or ammunition. Even the word "expedite" is streamlined in a combat engineer's vocabulary. The first waves of troops landing on beachheads carry a supply of water with them and produce additional small quantities with portable distillation units. As they move inland and a front is established the water supply engineer must develop and establish a more wholesale supply. The War Department Technical Manual on Water Supply and Purification covers

TABLE 3*

Daily Water Consumption—gal.

Unit Consumer	Conditions of Use	Gpd. per Unit	Remarks
Man (per capita consumption)	In combat:		
	Minimum	$\frac{1}{3}$ to $\frac{1}{2}$	For periods not exceeding 3 days.
	Normal	1	
	In bivouac:		
	Minimum	1	Drinking and cooking only, for periods not exceeding 3 days.
	Normal	2	
	Temporary camp:		
	Minimum	5	Drinking, cooking and washing.
	Normal	15	Includes also bathing.
	Field hospital	25	
	Semipermanent camp	50	Includes also water for baths, toilets, etc.
	Permanent camp	75	
	Permanent hospital	200	
Horse or mule, large domestic animals (consumption per animal)	Minimum	3 to 5	For periods not exceeding 3 days.
	Normal	10	
	Camps and cantonments	30 to 50	
Motors (consumption per vehicle)	Level and rolling country	$\frac{1}{8}$ to $\frac{1}{2}$	Depends on size of vehicle.
	Mountainous country	$\frac{1}{4}$ to 1	Depends on size of vehicle.
	Permanent camps	30 to 50	Includes washing.
Locomotives (consumption per locomotive)	Standard military	33,000	150 gal. per train mile.
	Commercial	50,000	200 gal. per train mile.

Note: These estimates must be modified according to circumstances, especially in hot climates. The requirements of the maximum month may exceed those of the average month by as much as 40 per cent.

* War Department, Technical Manual, TM 5-295.

the whole field. Here, as in the Engineering Design Manual, the average daily requirements are estimated and the water supply development attempts to provide at least the minimum requirements (see Table 3).

General engineer units are equipped with well drilling sections. The apparatus used most generally is a truck mounted, rotary type rig capable of drilling a 5-in. hole 1,000 ft. deep. For larger diameter wells a percussion type rig, with equipment for handling tools weighing from 1,400 to 1,600 lb. to depths of 600 ft., is provided. Most of the water supplies developed in North Africa were from drilled wells. The water supplies existing before our troops moved in were dug wells, both shallow and deep. The wells drilled

by troops were quite successful, although in many cases the water was quite saline.

The distribution of water in combat or in theaters of operations is accomplished by tank trucks or trailers and hand-carried containers. The lyster bag of World War I is still used with some modifications. This canvas bag holds about 36 gal. The site selected for distribution of water to one or several organizations must be such as not to interfere with the movement of troops or other traffic. It must be in a spot not liable to be observed by the enemy and the Commanding Officer must make the decision as to whether or not it is safe to set up purification apparatus.

Once the site is decided upon the water supply engineers must use their ingenuity because standards or precedents are the exception rather than the rule. The 3,000-gal. canvas tank may be either elevated on an improvised trestle or set on flat ground. It has been found that tanks on the ground serving as direct suction for pumps cause more spilling with resultant mud and bogs around the water distribution point. Not only does this waste water impede movement of troops and equipment, but the wetted area enhances the possibility of enemy observation. Elevated tanks can rarely be erected to a height sufficient to provide a satisfactory working head, so that if distribution is to be expedited the higher pressure from pumps is necessary. The 3,000-gal. capacity standard tanks are also used for sedimentation tanks where turbid surface waters are the only available source.

All of the equipment necessary to distribute a safe potable water must be erected and placed in operation by the water supply battalion in 24 hours. This equipment includes mobile and portable purification units in addition to tank pumps and whatever piping and hose are necessary. Piping is used sparingly as it must all be portable and trucked from one point to another.

Gatherings of water works engineers and others are certain to be favored by the presence of veterans to tell with words and pictures about water supplies in the Aleutians, in Europe, Africa, Asia and the South Seas.

Restoring Manila's Water System to Service

By Lloyd K. Clark

Project Mgr., Sanitation Research Project, Assn. of American Railroads, Baltimore, Md.

A contribution to the Journal

ON February 6, 1945, an advance echelon of the 5202d Engineer Construction Brigade pulled into the northern outskirts of Manila. This unit, headed by Col. S. E. Liles, C.E., was assigned to the 6th Army and its mission was to start the immediate rehabilitation of the facilities within the city, such as bridges, streets, lights, docks, and water and sewage systems. The Japs were making it pretty tough for the combat troops, although they had been driven out of most of the city north of the Pasig River. It was soon found that there was plenty of work lined up without getting into the south side right away. Apparently, the Japs, upon seeing that evacuation was inevitable, decided to do all the damage they could before retreating. The destruction they wrought is well known to all. The water system was not excluded.

On the morning of February 7 we made contact with Manuel Mañosa, Assistant Director of the Metropolitan Water District. Mañosa had been in touch with our combat troops even before their arrival and he had attempted to reach them in order to offer his services. He had been with the Water District many years and had stayed on during the Jap occupation. The retention of Mañosa should not be interpreted as collaboration on his part. No Filipino was more patriotic than he—his story, when it can be told, will make many hours of wonderful reading. Suffice it to say at this writing that every American of the three thousand interned at Santo Tomas will always be grateful to him.

We learned from Mañosa that the enemy had blasted all of the bridges crossing the Pasig River, thus severing service mains to the south side which crossed on these bridges. Water pressure on the north side was very low and continually dropping. Mañosa did not know the extent of any other damage to the system because he had been unable to travel about the city. The few vehicles that remained with the Water District had been taken to the Water District office and warehouses on the south side, which were still in enemy hands. He told us that the Director of the Water District, A. Magsaysay, and he had anticipated the probable trend of the American occupation of Manila and had arranged the formation of two Water District offices, one for the south side, headed by Magsaysay, and one for the north side, headed by Mañosa.

No plans of the water distribution system were available, because they were stored in a vault in the District office building. Mañosa was urged to search for plans and to start recruiting

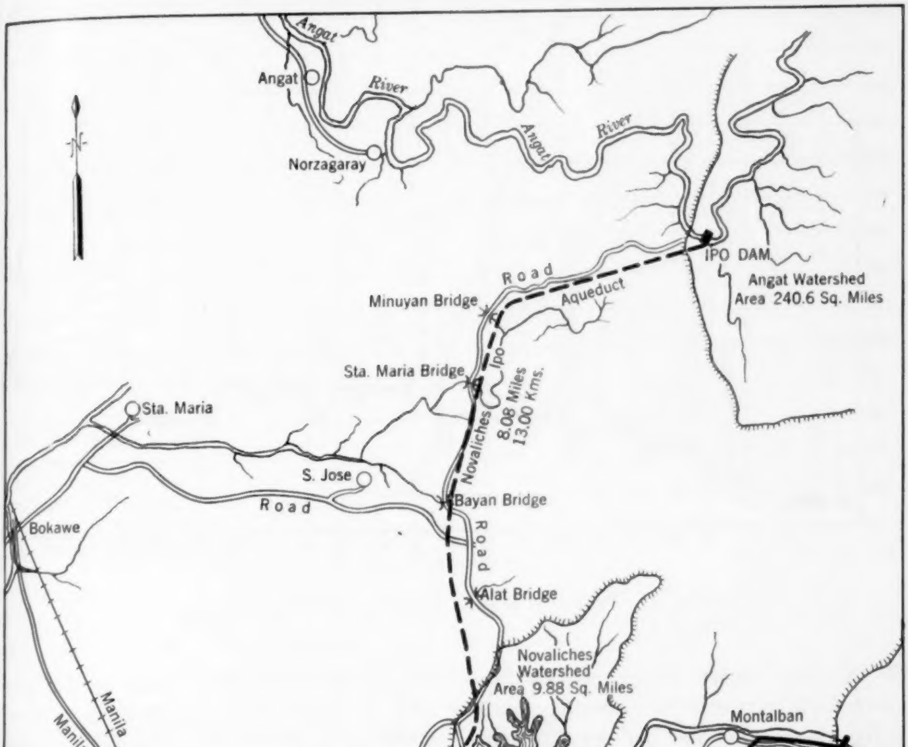

FIG. 1. Manila Metropolitan Water District

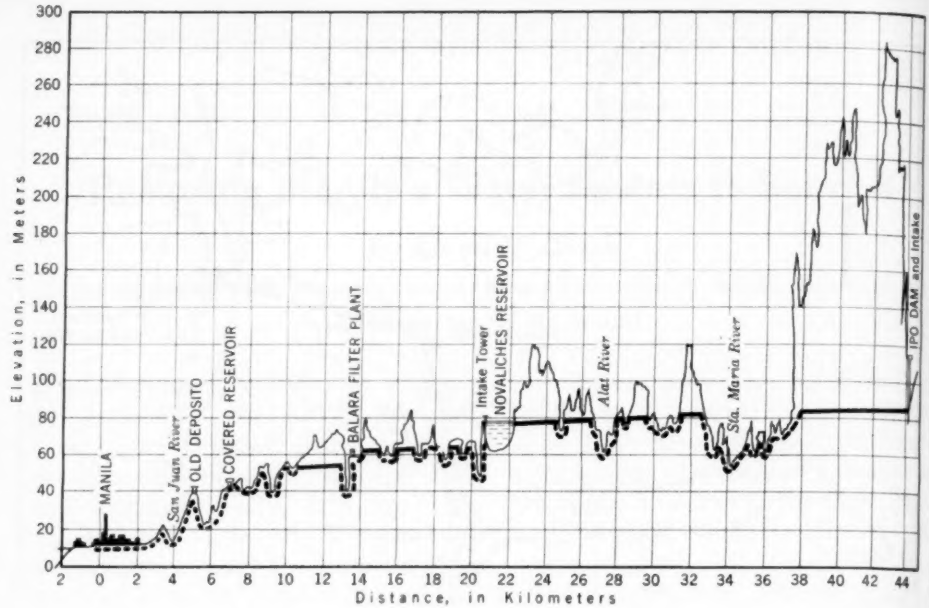

FIG. 2. Profile of Manila Pipelines and Aqueducts

all of the former water works employees (fifteen men had already voluntarily reported) and to set up temporary office space on the north side.

Briefly, the Manila Water System is supplied from two sources. One source is the Angat River at which Ipo Dam (Fig. 1), a concrete overflow structure, diverts water through a series of tunnels, siphons and gravity aqueducts (Fig. 2), running southwesterly about 13 km. to the second source of water, namely, Novaliches Reservoir. This reservoir, which has a total capacity of 9 bil.gal., impounds the Novaliches River and tributaries and stores water from the Angat River. It is located about 15 km. northeast of the city. It supplies water by means of an aqueduct to Balara filters, located about 7 km. northeast of the city. The 50-mgd. filter plant includes coagulation, settling, filtration, aeration and chlorination (Fig. 3). The treated water is sent direct to the city and to San Juan reservoirs, one of which is a 10-mil.gal. covered concrete structure and the other a 50-mil.gal. open concrete-lined basin not in service. Most of the city distribution system is fed from San Juan Reservoir, although the Cubao pump station draws water from the aqueduct which leads to the reservoir to furnish an area lying at a higher elevation and to furnish water to a long main which crosses the Pasig River on a suspension bridge to reach Fort Wm. McKinley.

From San Juan Reservoir, large mains (one 26-in., one 48-in. and one 54-in.) carry water into the heart of the city and to the mains which crossed the bridges to the south side. These bridge crossings replaced two underwater crossings which are still connected. The Japs forgot these crossings, or at least overlooked them in their demolition program.

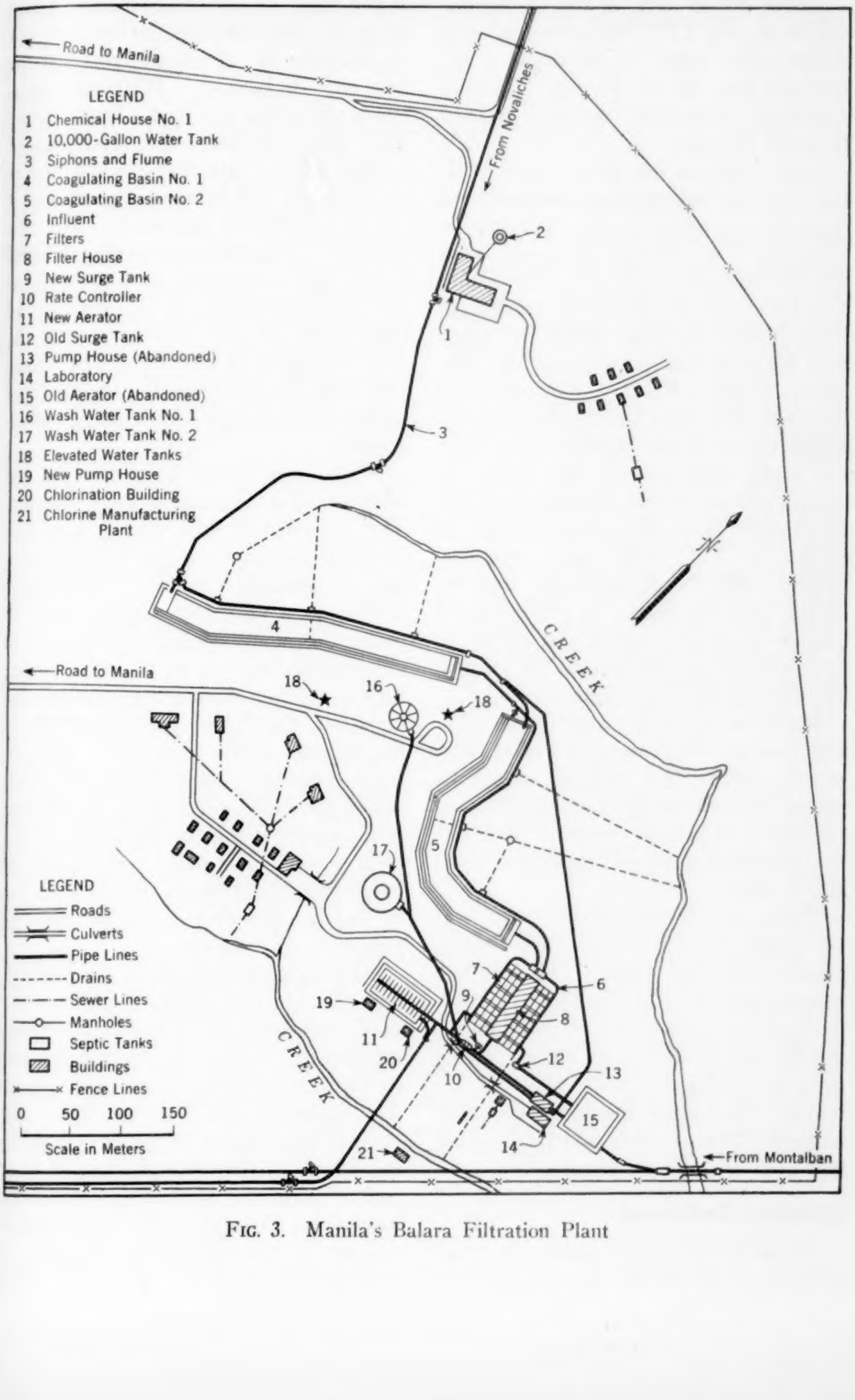

FIG. 3. Manila's Balara Filtration Plant

About 60 per cent of the metropolitan area, or 1,025,000 persons, was served with water. Consumption before the war was 40–50 mgd. During Japanese occupation usage increased to about 62 mgd.

After Mañosa left us we were notified that the Balara filters had been recaptured, so early in the morning of February 8 we drove out to see what was left, fearing the worst. We found the 1st Cavalry Division in charge. They stated they had taken the plant at 7:00 P.M. the evening of the 7th. Jesus Perlas, Plant Superintendent, who also had remained during the occupation, told them they had come none too soon, because the Jap officer in charge had previously warned the plant employees that the plant would be blown at 7:30 that same evening. About 1,500 lb. of dynamite was removed from the plant. It was wrapped around large gate valves and piping in the pipe gallery and around the pumps. No damage had been inflicted.

Many water works men in the U.S. and Europe will remember Perlas, who several years ago visited numerous plants on a carefully planned itinerary on which he keenly gathered and exchanged laboratory and treatment ideas and technics.

From outside appearances, the water plant resembled anything but a place for treating water. The Japs had camouflaged the filter building by seeding grass on part of the roof and painting the rest of it. Vines were growing over the outside walls. Most of the windows and other openings were sandbagged. The grounds and landscaping had seen no care for three years.

Chemical Treatment

Perlas escorted us about the plant which was delivering water to the city at the time. Very little treatment was being provided because he had run out of coagulating chemicals during the first part of January. Without coagulation the filters received a fairly heavy load and filtration was complicated further by the fact that electric power to the plant had been disrupted and it was impossible to backwash. For this reason they had become so clogged that it was not worthwhile to filter and, at the time we were there, Perlas had them shut off and was bypassing the water directly to the city. The filters had been in operation for about three weeks without any backwashing whatsoever.

Water was being disinfected by the addition of a chlorinated lime solution. The chlorinated lime was a Japanese product and contained a low percentage of available chlorine. They were feeding at a very low rate in order to make the small remaining amount of chlorine last as long as possible. Also, for disinfection during the Japanese occupation, there had been installed, in the vicinity of the filter plant, a small-scale chlorine manufacturing plant, which produced chlorine by an electrolytic process using salt obtained from a local dealer. The plant was capable of producing about 80 lb. of chlorine per 24 hours; however, with the lack of power, it was useless.

Although the upkeep of the grounds and the exterior of the buildings had been neglected, the interiors were well maintained. All of the equipment was in reasonably good shape and repair. The chemical and bacteriological laboratory was located in a separate building which, at that time, happened to be just outside the perimeter established by the 1st Cavalry. We were able to inspect it by ducking our heads and making a beeline for the door, which

was not more than 200 ft. outside the perimeter. Through field glasses we could see a few Japs across a coulee from where the plant was located. The laboratory was in excellent shape and undamaged. The equipment was in good shape except for one of the microscopes, the ocular of which apparently stuck to the fingers of someone.

Some Pre-liberation Plans

Perlas had not been unmindful of the fact that someday his plant would be liberated. For this occasion he had managed to cache about a month's supply of lime and alum for coagulating, and fifteen 150-lb. cylinders of liquid chlorine. Anticipating the probable destruction of the chlorinator building, he had obtained permission from the Japanese authorities to remove the two Wallace & Tiernan solution feed machines from the chlorinator building. These he stored in his house and it was possible to reinstall them a few days later in a matter of a few hours.

We left Perlas in the good hands of the 1st Cavalry boys and went back to our camp. The plant and the grounds, however, remained a sort of battle ground for several weeks. Perlas' backyard was the site of a mortar emplacement for many days. Naturally, there was some return fire from the Japs and, although it appeared to be simply harassing fire and very poorly directed, they did hit the building which housed the backwash pumps and some high-service pumps. They blew out the doorway at the pump house but damaged only one pump, a switch panel and a pressure gage. They also hit the aerator and broke off one 12-in. header pipe and several distributing pipes.

Perlas had converted an old presedimentation tank into a swimming pool which the combat troops liked so well that the plant and the grounds were eventually converted to a rest area. During those days that was about the only place where there was a good supply of water for bathing and cooking.

Novaliches Dam Supply

When we got home that night the 1st Cavalry had reported the recapture of Novaliches Dam. We drove out there early the next morning and found the entire installation undamaged and untouched. The Japs had planned to do some damage at the reservoir because several hundred pounds of dynamite were removed from the outlet well. The reservoir was not full and it was calculated at the time of our visit that there remained approximately 5 bil.gal. Outlet gates were located low enough to permit withdrawal for approximately two months, assuming a daily consumption of about 50 mgd. It was also assumed that no water would be coming from the Angat River which was still in the hands of the Japanese and destined to remain so for some time. With the aid of a patrol, we made our way to the point at the reservoir where the aqueduct from the Angat River emptied into the reservoir. We were very happy to find a good flow coming into the reservoir from this source. Unfortunately, the Japs fixed that a few days later.

On February 9, pressure in the distribution system fell to practically zero. Only a trickle of water would come from taps located at ground level. Of course, there were many reasons for that. Because of enemy sniper fire, some of the main line valves could not be reached and it was therefore impossible to shut off the flow that was escaping from the broken pipes at the

FIG. 4. The Filipinos' Struggle for Water

bridge crossings. Other valves could not be found, and still others were of left-hand thread and the men did not know whether the valve was closed or open. The widespread fires had resulted in thousands of service connections being opened. In addition, the Filipinos made it very difficult to conserve water because of their mania for bathing themselves and washing their clothes. They came to the hydrants continually with all sorts of containers, as shown in Fig. 4. When water failed to come out of the hydrants, ingenious Filipinos would crawl into gate valve manholes and remove the bonnets of the gate valves, thus flooding the manholes and making available to them and their neighbors a supply of water. One of our biggest jobs in the rehabilitation work was to replace valve stems for gate valves and hydrants. For all practical purposes, on the evening of Feb. 9, 1945, there was no water in the city distribution system.

While we had been making reconnaissance of the water system, Mañosa was busy calling in the former employees. He was able to get temporary office space in a building close to his own home. Many of the former employees came in voluntarily. Most of them were very hungry and they begged for work if they could only be repaid with a little food. Many persons had been reduced to boiling weeds for food.

Emergency Sources of Supply

With the lack of water in the city system it was evident that water had

to be supplied from some other source to meet the daily needs of the thousands of civilians. Fortunately, there were over twenty usable artesian wells located throughout the city which had been installed by the Metropolitan Water District. Few of these wells were flowing, but they were all provided with hand pumping devices. People were lining up at these wells to take their turn at filling water containers. The 1504th Engineer Water Supply Company had already been assigned to the 5202d Brigade. They immediately set up water points on the artesian wells, some small streams running through the city, the Pasig River, and on the abandoned reservoir in San Juan. A hurry-up call was made to headquarters back up the valley for the 1520th Water Supply Company, which arrived in jig-time and was followed by part of the 1519th. They also asked for a fleet of trucks to transport water. The trucks started for Manila the same night word was received at headquarters. About two days later there were ten mobile water purification units in operation, furnishing water to 65 water trucks which transported the water to 26 distributing points located throughout the city. Approximately 1 mgd. was dispensed in this manner. The water trucks were simply 6×6 cargo or dump trucks with a Navy ponton cube mounted on the bed and having a filling hole cut in the top and an outlet pipe and valve located at the bottom. These had to be made up after the trucks reached Manila.

Most of the distributing points consisted of 3,000-gal. canvas water tanks set up off the ground a few feet where possible, and these tanks fed into a header pipe on which a number of faucets were located so that several individuals could fill their cans at the same time. All of the water was heavily chlorinated and, with the invaluable help of 1st Lt. William Lee, Sanitary Corps, daily samples were taken for bacteriological examination. These samples were run in a small portable laboratory that Lt. Lee had brought into Manila with him.

It didn't take long to find out that much of the water transported to the civilians was being used for washing and miscellaneous purposes other than drinking; therefore, crews were made up from the Water District employees who were reporting and they were furnished with picks and shovels and empty steel gasoline drums. These crews went about the city and dug shallow wells to a depth of 6 or 8 ft., using the empty drums with the tops and bottoms cut out for curbing. These shallow wells tapped a shallow water table and made available to many persons water that was satisfactory for washing and bathing. During the two weeks that the water system was out of service, there were 46 of these shallow wells dug and put into service.

As previously mentioned, we were handicapped by lack of plans of the city distribution system. Mañosa did locate drawings for three districts and these helped some. Because we were not able to get to the south side, it was assumed that the plans that were stored there would be damaged, so the draftsmen went to work on an entirely new plat of the distribution system. They started drawing the mains in from memory and as the various lines were discovered during the repair operations. It should be mentioned in passing that the pre-invasion intelligence on the city water system was very good. We had a good accurate picture of the over-all layout before we entered the

city. Lt. Cesar Cabrera, a Filipino guerrilla, joined our outfit on February 3. He was a former engineer in the Metropolitan Water District and he rendered much assistance in guiding and in intelligence work.

Besides starting the major repair work immediately, one of the first jobs was to shut off the service connections. For this purpose we found that crews made up of former clerks and meter readers of the District worked out very well. All service connections were provided with a service cock at the time of installation and in most cases it was possible to shut off the water by closing this cock. In some places where damage to buildings was heavy, it was necessary to shut off the main itself. The crews were able to give us information in the office which permitted accurate layout maps to be made of the burned areas. Our plat of the burned areas showed about 35 per cent of the north side and 75 per cent of the south side leveled by fire.

Repair of Enemy Damages

On February 11 the flow into San Juan Reservoir stopped. Investigation revealed that the night before the Japs had blown out two sections of the 72-in. reinforced concrete aqueduct leading from Novaliches Reservoir to the Balara filters. The damage occurred at a point approximately 1,000 ft. from the reservoir outlet. Damaged sections totaled approximately 60 ft. in length and repair work was started immediately. The new line was made up of reinforced concrete, using, insofar as possible, prefabricated forms made of wood. The Japs tried to interfere with this repair job and, on several occasions, they had to be chased out of the gravel pits before the crew could start hauling gravel for the job. Also, they came in one night and blasted a nearby blow-off valve. This damage was repaired simply by extending a manhole up into the air far enough to place the top of it above the hydraulic gradient of the flow in the pipe. These repairs were completed and the line returned to service on February 24. This was one of our toughest jobs and much credit is due Lt. Col. C. Elder, C.E., and Capt. M. Noth, C.E., supervising officers, and the men of the 43rd Engineer Construction Batallion and the Metropolitan Water District.

The broken aqueduct was not the only damage inflicted by the Japanese. The first damages discovered were located at the San Juan Reservoir. Here the enemy dynamited a section of the cast-iron outlet pipe of the covered reservoir. A 15 × 20-ft. section of the reinforced concrete wall of the reservoir surrounding the pipe was also blasted out, together with a 48-in. gate valve and a cast-iron tee (Fig. 5). The demolition crew that did this work was not very observing because within 300 ft. of the blasted area there was a new 48-in. valve lying out in the open on the ground. With the exception of the damage to the aqueduct near the Novaliches Reservoir, this damage was probably the most important to repair, since the entire gravity system for the city had to pass through the damaged section in order to take advantage of the storage offered by the reservoir. It was possible to bypass the reservoir during repair operations which were carried on simultaneously with the repair of the aqueduct. The new 48-in. valve was inserted and the broken cast-iron pipe was replaced with a section of reinforced concrete poured in place. This work was also completed on February 24.

FIG. 5. Result of Jap Blasting of San Juan Reservoir Outlet and Gate Valve

The covered reservoir and surrounding area seemed to be a favorite target of the Japs and artillery shells fell sporadically in that vicinity during most of February. The covered reservoir caught a few direct hits on the top in the walls, but none of the holes were larger than 4 to 6 sq.ft. They were repaired simply by patching.

Also discovered at San Juan was the demolition of a 48-in. gate valve located on the outlet to the open reservoir, together with a 48-in. gate valve located on an adjacent bypass line also connected to the open reservoir outlet pipe. Reducers to the valves were also broken. The open reservoir had been maintained full of water so that when the one outlet valve was blasted it released water into the system. Since the system was practically drained anyway, we let this water run, chlorinating it right at the valve with a drip-feed chlorinator device. The amount so obtained, however, was not enough to maintain anything more than a small supply to part of the system and it gave no pressure. As soon as the water in the open reservoir had run out, the outlet pipe was sealed off, using an undamaged shear gate of one of the broken valves. The other 48-in. gate valve was replaced by a 42-in. valve that was stored in the District stock pile. Two reducers were made in a rolling mill by fabricating the pipe and flanges from steel plate. This work was completed on March 19.

Two large mains carried water from the San Juan Reservoir to the city distribution system. At a point about 500 ft. west of the open reservoir, one of these mains, a 54-in. cast-iron pipe, was blasted in two places. This damage was repaired by inserting a total of about 40 ft. of new cast-iron pipe of the same size and the work was completed on February 20.

All of the repairs cited above were made by engineer troops and by the civilian employees of the Metropolitan Water District. The repairs were accomplished in spite of considerable enemy action, consisting of directed machine gun fire, sniper fire and direct shelling. Patrols and guards were required for protection on several occasions. Much of the work was done on a 24-hour basis and, of course, it was necessary to use flood lights even though the rest of the city was completely blacked out. It was necessary for some of the crews to work straight through for 24 to 36 hours without relief, and this applied to the Filipino crews as well as to our own Army troops. These men worked without regard to their own safety and great credit is due them for their devotion to duty.

The aqueduct from the treatment plant to the San Juan Reservoir passes through the Rosario Heights District which, together with some adjacent districts, is at an elevation too high to be served by gravity. The Cubao pumping station was located along this line to deliver water to two elevated storage tanks of 300,000-gal. capacity. This pumping station was blasted almost beyond recognition. It contained six pumps with electric motor and diesel engine drive with a total pumping capacity of 4,150 gpm. It was possible to salvage only two pumps; none of the motors or engines could be salvaged or rebuilt. We were handicapped by the lack of large-capacity pumping units, but it was possible to install and place in operation one 500-gpm. portable gasoline-engine-driven pump and one 1,000-gpm. diesel-engine-driven pump by March 21. The diesel engine for this last pump was obtained from an Engineer Boat and Shore Company of the 3rd Engineer Service Brigade.

Fort William McKinley, located on the north side of the Pasig River at the eastern city limits, had been developed into a fairly large Jap installation. It was formerly a post established by the United States Army. During the Jap occupation, due to increased water consumption, the District installed a new 12-in. main. This new main crossed the Pasig River on a suspension bridge. The retreating Japs placed a demolition charge out in the center of the span of the suspension bridge and blasted it in two. Repair of this damage was not difficult, although the suspension cables, as well as the pipe and supporting walkway, were broken. Most of the pipe and cable was salvaged from the river as the shore ends were still connected to the piers. One suspension cable was spliced and the other cable was replaced by a new line which was found in a downtown warehouse. The repair work was started on March 5 and finished on March 12. The over-water span for the bridge was 270 ft.

At El Deposito, which was an old underground reservoir built during the Spanish regime, a 26-in. gate valve was blasted. This valve had been used as a plug and the damage was repaired by merely inserting an improvised plug in its place.

In addition to the blasting of the bridges crossing the Pasig River, a large number of bridges crossing the esteros (canals) were blown up. Twelve-inch mains usually crossed on these bridges, but the repairs were not difficult, since the span was usually not more than 20 ft. and the pipe could be supported on timber trestles or bridging. Five of these crossings were repaired and put into service by March 19.

Treatment of Resumed Supply

With the completion of the repairs to the major damages on the system, water was again released from Novaliches Reservoir on February 24 and it reached the city system the next day. No coagulating chemicals were added at the treating plant and the filters were bypassed. Chlorine was added, using the solution feed machines and the supply of liquid chlorine that Superintendent Perlas had been saving. This supply of chlorine was supplemented by chlorine from the small 15-lb. cylinders used in the mobile purification units. The content of the small cylinders was transferred to a 150-lb. cylinder, and if you think that is easy in warm weather, just try it! Perlas rigged up a stand which held a small cylinder over the large one. Two hoses played

cool water over the cylinders. The chlorine dose was kept at 2 ppm., which was sufficient to carry through into the distribution system. Chlorine residuals were checked every day throughout the system by men assigned to that specific task.

It was obvious that the chlorine supply was limited, so the operators of the chlorine manufacturing plant were instructed to get it back into operation as soon as possible. It turned out to be a very slow process, however, as they were handicapped by lack of proper supplies and equipment. Hurry-up orders were placed in the States for supplies of chlorine and coagulating chemicals.

It was not possible to get power out to the treatment plant until the latter part of February. As soon as it was available, however, Perlas started backwashing and cleaning the filters. That was a real job. It was necessary to backwash five to seven times using, in addition, surface washing from high pressure hose. Nine of the ten filters were cleaned by the end of March.

Repair of Distribution System

No repair work was started on the city distribution system prior to the reopening of the supply line on February 24 except for the replacement on Rizal Avenue of six lengths of 16-in. cast-iron pipe which were damaged by bombs. With the return of water to the distribution system it was soon apparent that our job had just started. Leaks seemed to appear from everywhere. People clamored back to the open hydrant valves, and many that were not open, to get city water for drinking and to satisfy their pent-up desire to wash. For this reason it was difficult to build up pressure. At first a roving car was used to carry men who shut off hydrants that had been opened promiscuously. In most cases, however, as soon as our men drove away, someone would come up with a wrench and open the hydrant again to draw a pail of water or to take a bath. This would not have been so bad had t not been for the fact that, after getting the water they desired, many persons would walk away and leave the hydrant running. Many times we found a 4-in. hydrant running full blast on one person taking a bath. We finally solved this trouble to some extent by assigning to a certain district an individual whose job it was to patrol the district all day and close the valves as soon as they were opened.

Perhaps the greatest loss of water in the system occurred in the widespread burned out and shelled areas. Inspection crews found leaks and shut off service cocks wherever possible. Fifteen day crews were organized to make the repairs of the leaks and the breaks. Two crews were assigned to work a night shift. As of the 20th of March, 929 leaks had been repaired on the north side of the Pasig River.

One cause of leaky mains was the Army traffic. Heavy trucks and tanks bouncing over the rough streets ruptured the pipe which was laid only $2\frac{1}{2}$ to 3 ft. below the surface of the ground. In many cases the pipe was not broken but the joints were loosened sufficiently to cause them to leak.

After water pressure was restored to the distribution system at least in amount sufficient to give pressure at the hydrants, it was necessary to devise a dispensing fixture so that people could take the water from the hydrants. We were able to find a number of fire hose connectors and these were brazed to a 3-ft. header of 4-in. pipe to which were welded four $\frac{1}{2}$-in. or $\frac{3}{4}$-in. faucets.

Steel rods were welded on the header as legs to support it and the connection was made to the threaded opening on the hydrant and the hydrant valve partially opened. In this way it was possible to save a lot of water and at the same time give better service to the civilians.

As soon as the Japs were driven out of the south side a large number of the existing buildings were occupied in the vicinity of the dock area. This required the early restoration of water to that section. A 12-in. line was relaid on the Bailey Bridge, which replaced the Jones Bridge. In addition, a pumping station was set up on the north side of the Jones Bridge to pump from the mains on that side through a 6-in. service line to various units on the south side. There was not enough pressure at first to force water through the 12-in. main up over the bridge and into the dock area system. The new 12-in. main across the Bailey Bridge was simply connected at both ends to the old main which projected through the bridge abutment. In making the connections it was necessary to do considerable work with air drills and sledges in breaking out the concrete near a manhole which was located about 15 ft. from the face of the abutment. Such activity, especially with the concrete breaking equipment, proved to be a very hazardous undertaking, as we shall see later, although it was entirely unbeknownst to the workers at the time.

Another reason for serving the dock area at an early date was to furnish water for ships already unloading at the piers. Naturally, all of the existing water lines on the piers were badly damaged.

It was necessary to make repairs on an elevated storage tank located in the dock area. This tank, of approximately 100,000-gal. capacity, was mounted on concrete walls at an elevation of about 80 ft. above the ground level. For some reason, either the Japs or our own artillery had opened up on this tank and punctured the wall in seven places. There was no evidence that any troops had ever taken up a location inside of the tank. These holes were repaired by patching.

The Santa Anna and the Makati districts, located on the east side of the city just across the Pasig River to the south were furnished water at an early date. As stated above, the Japs forgot two underwater crossings in their attempt to isolate the south side. One of these, a 30-in. main, supplied the two districts, and that line was opened during March.

Many handicaps were encountered in making repairs. The Water District shops and warehouses, located near the District office buildings, were inaccessible for many days. Some calking tools, oakum and lead for making joints had been stored in a sewage pumping station on the north side and they came in very handy. It was necessary to make additional calking tools, valve turning wrenches, valve stems and many different types of fittings and connections. We were fortunate in having available the services of the 692d Engineer Heavy Shop Company and the men in that outfit turned out practically anything and everything we wanted as long as we could furnish the raw materials.

Fortunately, the larger sized pipes, valves and fittings were stored in a large area in the vicinity of North Harbor. The enemy did no damage to these valuable supplies as they were forced to vacate in too much of a hurry. Although many items for quick repair

were not found in the storage area, it was possible to substitute and thereby facilitate the return of much of the system to service.

Transportation was a big bugaboo during the early months, but before the end of March we were able to obtain ten Army trucks and have them assigned to the Water District for its use alone.

Re-establishment of Water District

The reorganization of the Metropolitan Water District was accomplished with surprisingly little difficulty. Undoubtedly, this was because it was well organized before the war and had not been particularly disrupted during the Japanese occupation. Moreover, most of the employees were very loyal, many of them having worked for the Water District for more than twenty years. The Director, and the Assistant Director, were very well qualified professionally and they administered the organization with efficiency and dispatch. The office space Mañosa obtained on February 8 on Azcarraga Street served as headquarters for about two weeks. He was then able to secure a building and lot across the street at 2219 Azcarraga Street, and this new headquarters provided storage space for supplies and equipment besides housing all of the office personnel. As with other outfits doing repair work in the city, we were able to offer the workers rations of canned fish and rice which encouraged many of the workers to return. Common laborers started out at a wage of one peso per day. The daily ration included about one quart of rice and one can of salmon. The cost of the ration was deducted from the worker's wage. For a time the Philippine Civil Affairs Unit allowed extra rice to be cooked for the workers' noon meal, but this was later discontinued.

The recruitment of the former employees took place rapidly. Fifteen men reported to Mañosa on February 7. By the end of the month there were 345 employees reported and working. By the end of March there were 558 employees. Mañosa directed the reestablishment of the Water District. Magsaysay, the manager, had remained on the south side and of course it was impossible for him to report in until after the Japanese were driven out. He and his family escaped unharmed. He made his way to the north side and reported to our temporary offices on February 21.

While we were trying to get established on the north side during the early days of the occupation, we often looked longingly to the south side where we could see the Metropolitan Water District building. This was a large three-story reinforced concrete structure with attractive stone facing. The building was left completely intact by the employees upon the arrival of our forces at the north side of the city on February 3. There were many fine office supplies and equipment, as well as a very extensive library. The workshops and bodegas on the same lot housed modern machinery and meter testing devices, as well as a complete foundry. The Japanese required the employees to park all of the Water District trucks and automobiles in the District garage located in the same area. We were in hopes that all of these things would be left undamaged, because they would be so useful in the rehabilitation of the system.

After making two attempts to reach the Water District buildings we were finally successful on February 23, but, to our sorrow, we found that the office

building had been occupied by the Japanese combat units, with the result that the building was not only badly shot up from our own artillery fire, but when the Japs retreated they set fire to everything except the foundry. The building offered a good point of resistance and the Japs made the most of it by breaking out the concrete on the ground floor and making dugouts below it. On top of the dugout opening they placed huge wood timbers for additional protection. Guns of various caliber were mounted on the different floors in the building.

The building was being used as a CP by our own troops when we arrived. Of course, the treasurer's vault had been blasted open in an attempt to find some "good" money. The looters were not interested in the "Mickey Mouse" money and left stacks of it all over the vault. In one corner the paper money was about three feet deep and ranged in denomination from 50 centavos to 100 peso notes. An artillery shell had pierced the top section of the second story vault but the door itself had not been forced and no one had made an entry into it. The door had to be opened with heavy tools, so we had to come back the next day to get into the vault. In the meantime, in our absence, the combat troops made a reconnaissance and removed a considerable amount of personal property which the office employees had placed in the vault prior to leaving the building. But we rejoiced in finding nearly all of the maps and plats and plans pertaining to the water distribution system and to the sewerage system. This was a great victory because we were so handicapped up to that time without such material.

While we were visiting the District Office building on the morning of the 23rd, large numbers of Filipinos just liberated from the Walled City were making their way past the building. This was a pitiful sight. These people had been subjected to continuous artillery fire and dive bombing for many days, in addition to the widespread fires set by the Japanese. All their worldly possessions were carried with them, and usually they made no more than an armful. During the two hours we watched them file past the building we saw only two grown men and very few small boys—mute evidence that the Japanese butchery was somewhat confined to the male sex in that particular section.

After surveying the situation at the District buildings, a crew and truck started hauling what salvage material they could pick up out of the ashes and wreckage. A large number of smaller size fittings were salvaged and, although they were burned, it was possible to put them in pretty good shape by brushing them with wire brushes and oiling them. All of the material was hauled to the temporary warehouse area set-up on the north side of the river.

Distribution System Survey

As stated before, one of the first projects was the use of the older office workers and the meter readers to form small crews to survey the extent of damage and to shut off service cocks. They also read the meters wherever possible. By the end of March these crews had read 19,194 meters, closed 7,882 service cocks and plugged 1,203 broken service pipes. On the south side alone, by the end of March, 9,567 service connections were found to be damaged or burned.

By the end of March, activity in Manila had pretty much settled down to the painstaking job of more permanent

rehabilitation. Much of the emergency repair work was completed, although activity was maintained at a very high pitch because our forces were getting ready for more invasions on the islands to the north. The first WACs had reached Manila, the Japs had been driven east to the vicinity of Antipolo, south to the vicinity of Batangas, and northeast to the vicinity of the Ipo Dam. It was not until the latter part of May, however, that Ipo Dam was freed so that water could be again diverted from the Angat River to the Novaliches Reservoir. The first train had arrived from Lingayen Bay and regular schedules were being set up for the transportation of freight and passengers from the north. The black market was flourishing, night life was in full swing, and poisoned liquor had already killed eleven soldiers and blinded four. It was reported that more than 100,000 Filipino children were back in school in Pangasinan Province.

And that about winds up the story of the first two months of rehabilitation of the Manila City Water System. By that time the 5202d Brigade had established a Luzon Engineer District, under command of Col. O. E. Walsh, C.E., the water section of which was in charge of the author, and this section had the responsibility for the city water system. On April 1 a number of the city utilities were turned over to the General Engineer District, a new organization coming in directly from the States. Maj. L. H. Scott, C.E., well known in water works circles, took over the water section.

A Main Repair Hazard

There is a fitting sequel to this paper. It pertains to the manhole at the Jones Bridge north abutment. Shortly before the General Engineer District took over it was decided that since the installation of the 12-in. main across the Bailey (Jones) Bridge was leaking badly at the north abutment, it ought to be repaired. As stated earlier, there was a manhole located about 15 ft. from the end of the abutment. A number of us had been in this manhole to inspect the water main passing through it and repair crews had worked with air drills and sledge hammers in chipping off the concrete adjacent to the manhole. We decided to start the repair with a length of pipe which terminated in the manhole and lay a new length of pipe from there to reconnect with the pipe running across the Bailey Bridge.

Work was started once more by breaking concrete in and near the manhole when one of the Filipino workers noticed a layer of Japanese matting under the 12-inch. main passing through the manhole. He lifted the mat up and to his surprise he saw what appeared to be the tail fin of an aerial bomb. The bomb disposal crew was called in promptly and they confirmed our suspicions by taking out a 100-lb. bomb. While this bomb was being removed, they hit another piece of metal which turned out to be a second 100-lb. bomb. When the bomb disposal crew finished, they had taken out twenty-five 100-lb. bombs, two cases of dynamite, and a can of picric acid. You can well imagine the feeling of combined fright and relief on the part of everyone who had been working around that area.

We cannot close without a word of tribute to the many persons who took part in the early days of rehabilitation of the Manila City Water System and of the other utilities, for that matter. The intense interest and thoroughgoing dispatch exhibited on the part of

the officers and men of the 5202d Engineer Brigade and the Engineering Units attached to the Brigade were a glory to behold. The employees of the Metropolitan Water District were most faithful and loyal. Nor can we omit the 1st Cavalry Division which took the Balara filters and the Novaliches Reservoir before they were dynamited, thus saving for the city a supply of water and treatment facilities for the hundreds of thousands of people who would otherwise have had to go without.

Only one man was lost in the water supply operations. He was a sergeant of the 1504th Engineer Water Supply Company, who was shot by a Jap sniper while on duty at a water distributing point. It is regretted that his name is not available for publication here.

Taxation of Municipal Utilities

State Tax Commissioner C. Emory Glander announced on March 20 that all Ohio city-owned utilities, with the exception of transit systems, are exempt from real and personal property taxes. This is in accordance with the Ohio Supreme Court ruling of June 1945 that the Cleveland Division of Municipal Transportation was not exempt from taxation (Jour. A.W.W.A., **37**: 1293 (1945)).

The new ruling is based on a section of a nineteenth century Ohio law which provides exemption for "works, machinery, pipelines and fixtures belonging to a city or village and used exclusively for conveying water to it, or for heating or lighting it. . . ."

The Commissioner's decision has already been challenged in the Court of Appeals. In a taxpayer's suit the defendant has asked that the court compel Glander to collect taxes on real and personal property of every publicly owned utility *except water works.*

Okinawa—DDT and Water Treatment

By Alden E. Stilson

Cons. Engr., Alden E. Stilson & Assocs., Columbus, Ohio

A contribution to the Journal

OKINAWA! This is a name that will remain in the military history of the future and mark an important milestone in sanitary engineering progress. The specter of water-borne infections has plagued all men who have traversed the islands of the Far Pacific. For the first time in history a whole Army was sent to this area and is now returning free from this curse. Saipan, in July and August 1944, was the scene of wholesale illness among our troops, who suffered from dengue fever. A few magic passes of an airplane and the mosquito vector disappeared. Troops fresh from non-infected areas arriving on Saipan shortly after spraying did not suffer from this painful disease. Peleliu, lying but 8 deg. north of the equator in a thoroughly malarial and dengue infested area, was also sprayed by planes discharging DDT, with the result that mosquito-borne ailments were not a problem. Excellent data could be obtained from both Saipan and Peleliu, but probably the most extensive, and certainly the war's most successful, effort against all tropical diseases took place on Okinawa.

That successful effort stemmed from a careful study of Okinawa's topography and climate, its insects and its diseases. DDT and other poisons were studied for their effectiveness and possible danger in polluting water supplies. The War Department's water purification methods were carefully adapted to the demands expected on Okinawa and the immense program for materiel and supplies was worked out. Then came the pay-off in the campaign and finally a post mortem inspection of the sabotaged and wrecked Japanese treatment facilities.

The Island of Okinawa

Okinawa is about 64 miles long and varies in width from 2½ to 13 miles (Fig. 1). It is located at longitude 127 deg. 45 min. east and latitude 26 deg. and 20 min. north. The surface of this piece of land is composed of Kungami gravel or sand, Ryukyu limestone, Shimajiri limestone and raised reef coral. Below the surface are found schist, soft and hard slates, sandstones and considerable amounts of blue shale. These strata are perched upon Paleozoic or igneous rock of an ancient folded mountain chain. It is thought that the basic folds are contemporary with those of the Carpathian ranges of western Asia and eastern Europe. Where the ancient rocks of Okinawa are laid bare, they are said to resemble the other China folds of the Asiatic mainland, both chemically and physically. Dips, faults, synclines and anticlines are found. Natural limestone caverns floored with marl, blue clay and shale are scattered throughout the

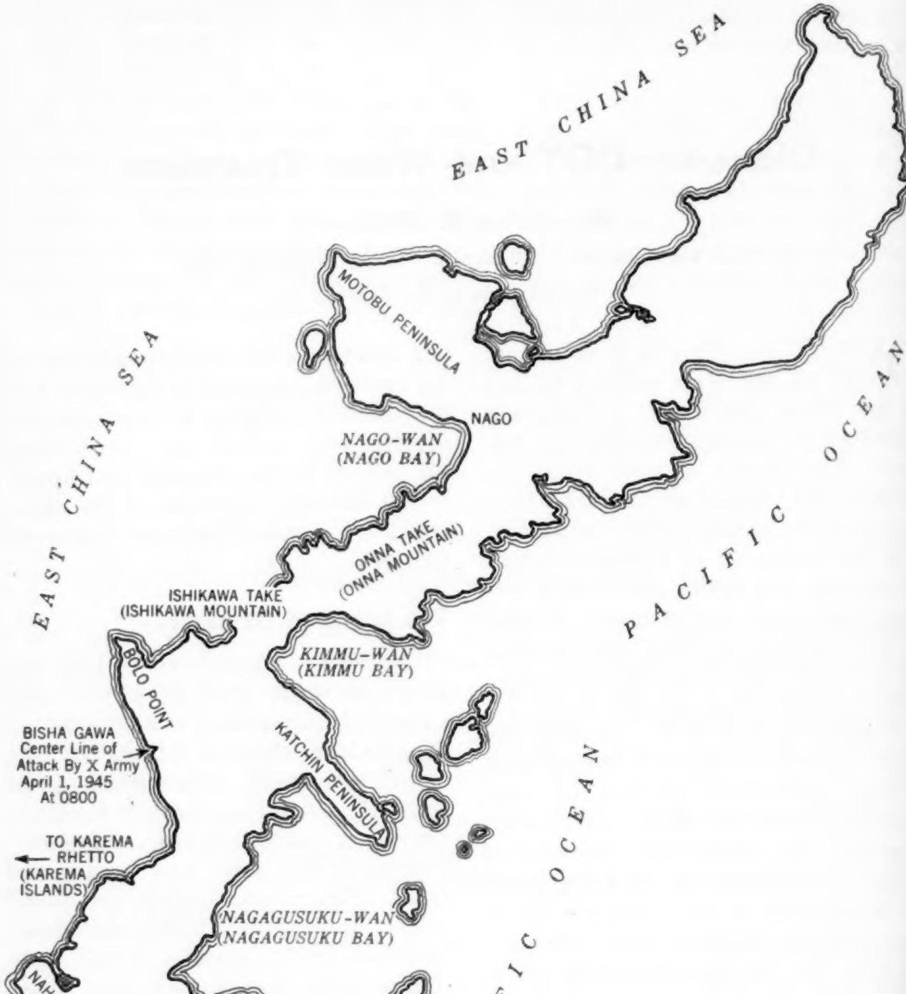

FIG. 1. Okinawa

island. These subterranean caverns are exposed where the slopes have been eroded by the elements and the sea; some of them are accessible and many act as natural water reservoirs.

Topography

Topographically, the island varies from rugged contours in the north to fairly level plateaus in the central portion. The southern area contains modi-

fications of both the central and northern parts. The plateau in the central section slopes gently upwards from sea level on the west to almost 250 ft. on the east. The easterly shore line is composed of long tidal flats ending to landward at the foot of coral beaches and rock cliffs. There are four principal peninsulas, each of which juts out from the main body of the island several hundred yards. The Chinen, Katchin and Motobu Peninsulas are rugged in the extreme, with many cliffs to seaward. Bolo Point is level, though it too has an uneven coast line. The Katchin Peninsula has a considerable amount of talus at the foot of some of its scarps.

Between Katchin and Chinen is found Nakagusuku-wan, renamed Buckner Bay for General Simon Bolivar Buckner, Commander of the 10th Army, who was killed during the Okinawa operation. This bay is slightly protected by various raised reefs lying from 6 to 8 miles off shore to the east and south.

Between Bolo and Motobu lies Nago-wan. This bay affords a small measure of sheltered anchorage. It faces northwest toward Ie Shima and other islands lying some 20 miles to the west. Except for the "ice-cream cone" on Ie Shima, there is no high ground of any consequence in the islands in the East China Sea. About due east of Naha lies the Karema Rhetto. These islands have low hills which range as high as 150 ft. and are approximately 8 miles off shore.

The island of Okinawa has several short, deep and narrow streams flowing principally from east to west. They are fed by seepage springs and the longest are about 3,000 yd. The few water courses in the north that flow east into the Pacific are typical mountain streams issuing from the narrow wooded valleys. They are due primarily to surface drainage.

Indenting the east central portion north of Katchin peninsula, there is a bay known as Kimmu-wan. This bay was made by the rapid runoff from the hill mass formed by Ishikawa and Onna Take. The hills range in height from 700 to over 1,000 ft. Their easterly slope is extremely rugged. They are composed of schist and Ryukyu limestone with underlying igneous and Paleozoic rock which was forced up ages ago. Near the center of Motobu Peninsula there is a sedimentary plateau resting upon what was once a drowned valley that subsequently has been lifted about 200 ft. above the sea. A large part of the island has a slightly submerged reef fringe composed of marl overlain with sandy deposits. The reefs extend outward for long distances and slope gently to sea.

Climate

The climate of Okinawa resembles that of northern Florida and southern Georgia. Rainfall varies from place to place on the island due to the wind currents induced by the hills. The humidity averages between 75 and 85 per cent, whereas the temperature will range from 40° to over 100°. The Pacific trade winds coming in from the north and east bring abundant moisture to the cliffs on the eastern coast. The island runs northeast-southwest. The south and southwesterly portions are shielded from the trade winds blowing in from the northeast by the high ground to the north and east. As a result, droughts may be experienced locally in and around Naha and on down as far as the escarpments at the extreme southerly tip. During the period from April to September, tor-

rential rainfalls were experienced periodically, due to the typhoons moving northeastward from Luzon and Formosa. At this time as much as 8 in. of rain fell within a period of from five to six hours. The peak of the typhoon and rainy season is experienced during the late fall and winter. Spring and early summer bring the best weather, though typhoons may come at any time of the year. During the Okinawa campaign there were two periods of semi-drought interspersing the heavy rainfalls, which proved disastrous to the Japanese forces in and around Naha and a matter for concern to the American troops. On the offshore islands in the China Sea actual drought is a common occurrence. In some instances the Japanese government found it necessary to import drinking water.

Insects and Diseases

Mosquitoes, flies, fleas and other insects are abundant in the Ryukyu Rhetto. These vectors were alleged, and in certain instances proven to be the carriers of malaria, dengue, Okinawa encephalitis, Japanese river fever (mite typhus), diarrheas, bubonic plague and filariasis. In July 1945, the Okinawa encephalitis appeared. It was identified as being Japanese B encephalitis. Natives who had remained in the hills of the north, beyond the control of the Americans, became ill with malaria in August. Dengue was suspected in June among a few of our own troops in the extreme forward areas. Diarrhea among the natives could not be attributed specifically to insects. A native's illness could usually be traced to a lack of sanitation. The mite, which carries mite-typhus, had not been specifically identified by September 1945. This dreaded disease was not reported on the island during the campaign. Filariasis was evidenced in many natives, particularly around Nago. Actual elephantiasis, the result of filariasis, was not commonly seen. No bubonic plague was found, nor were there any rat fleas carrying this scourge. Animal fleas infested houses, grass, vegetation, animals and natives. For a few days after the invasion our troops suffered from flea bites. Flies, both the common house variety and the green bottle type, swarmed everywhere on the island until brought under control. Ants were numerous but not a serious problem.

Some 300 natives, selected at random and apparently in good health, were examined for *Endameba histolytica*. The search revealed amebic cysts in 12.5 per cent of those checked. Only one stool specimen was studied from each person. Competent medical officers estimated that from 50 to 75 per cent of the natives either suffer from this infestation or can be considered carriers. A Japanese officer prisoner from the 22nd Water Regiment stated that practically every Japanese soldier arriving on Okinawa soon developed a dysentery which was presumed to be amebic. It was his belief that this strain of amebic cyst was not a virulent one. He reported that it had caused only a few deaths, which in his opinion did not warrant extensive water treatment. Examinations by our Army laboratory indicated that practically every native was infested with round worms and other intestinal parasites. Diarrheas of all types presented serious problems in handling native sanitation. These diseases were a constant threat to our troops. Cholera was not seen during the operation, though it was reported to have been on the island. Hog cholera serum was found

at a veterinarian's establishment near Ishikawa. A prisoner of war reported that he had been instructed by his Japanese officer to sabotage American water supplies with cholera but the information was not confirmed by other prisoners. No cholera organisms for sabotaging our water were captured. The natural habits of the natives were such that all water supplies were heavily contaminated and polluted directly with human fecal matter and all types of other septic material. The natives insisted upon using any available water for drinking, bathing and washing clothes. Defecation in the same water was common practice. Fecal matter was saved to spread as fertilizer on fields and rice paddies which drained directly into drinking water sources. All raw water supplies were found to be heavily polluted both above and below ground.

Larvicides

Plans for the campaign were commenced in September 1944. The larvicides decided upon were DDT (dichloro-diphenyl-trichlorethane) for mosquitoes and flies; dimethylphthalate for mite protection and sodium arsenite for fly control on decayed flesh. At the time, little was known regarding these several poisons. Experiments were in process by the Army and the Department of Agriculture but little reliable data had been developed. DDT had been used successfully in Italy to control plague, but the toxic effects on human beings were not yet determined. It was believed that DDT dust was not toxic to man except when inhaled in heavy concentration. DDT in oil emulsion was known to be dangerous when absorbed through pores of the skin. The quantities of this insecticide available in the Pacific were so small as to preclude large scale experimentation. During the dengue epidemic on Saipan, sufficient DDT was received to spray the island. The facts and figures were closely studied and the actual results observed, but no final conclusions were possible. Certainly the potential damage to water supply from DDT sprayed by plane could not be estimated. On Peleliu and Angar, DDT was sprayed by plane in November but, aside from the demonstrable effect upon flies and mosquitoes, no data as to its reaction upon water were recorded. Col. Walter B. Martin, M.C., experienced in internal medicine and chief consultant of the 10th Army, had observed the excellent results obtained from the use of DDT in controlling dengue and malarial vectors. He strongly urged using this compound to the maximum on the forthcoming invasion. He believed that sodium arsenite, properly used as a larvicide in latrines and for burials, would not endanger the health of the command. Reports indicated that dimethylphthalate gave protection from mites but irritated the skin. Col. Martin and Col. Homan E. Leach conceived the idea of testing the effects on themselves and others in the medical section of the 10th Army. Clothing was thoroughly impregnated and worn next to the skin for extended periods which included violent exercise. In this experiment no skin irritation appeared. As a result it was decided to use dimethylphthalate as a repellent for combat clothing.

Although the ill effects of DDT introduced in the water supply by reason of airplane spraying was a matter of concern to some, the staff as a whole was quite anxious that the material be used to combat insects. Lt.Comdr. Flaherty and Lt. Mapel, U.S.N., who

were killed during the invasion, had perfected workable equipment to provide airplane spraying of 10 per cent DDT in a mixture of diesel oil from Navy planes. The Army outfitted C-47's for the same work. The supplies of DDT were greatly augmented in January 1945 by increased manufacture, so that the War Department made available the many thousands of pounds of this material which had been requested for the invasion. It was estimated that over the 100,000 acres which constituted the inhabitable portion of Okinawa would be sprayed with at least $\frac{1}{8}$ lb. of DDT in 2 qt. of diesel oil per acre every ten days. Just what concentrations would reach the streams and what the physiological effects would be upon the troops presented questions that seemed impossible to answer.

About the middle of January, a small sample of DDT was obtained by the 10th Army for experimentation. A test of the hit-or-miss variety seemed to be the only way to solve the problem; therefore one of the officers of the 10th Army drank 1 qt. of water a day containing approximately 0.5 ppm. of DDT for a period of three weeks. No ill effects were observed.

Sodium arsenite had proven successful in preventing fly breeding in Guam and Kwajelein. No demonstrable arsenous compounds were detected in the water supply. On Saipan it was reported that arsenic was introduced in Doneh spring and Isley well as an act of sabotage by the Japanese. Capt. Elmer Campbell, Chief Engineer of the State Health Department of Maine, on leave to the Army, was consulted in regard to the use of arsenous compounds. His previous experience satisfied him that no danger to the water supply would accrue from controlled use of this substance on ground at a considerable distance from a water source. The entomologist of the 81st Division on Angar conducted some experiments in connection with the use of sodium arsenite. His field experiments were necessarily crude but indicated that little or no arsenic would penetrate through 1 ft. of coral sand. The ability of coral sand to absorb water and hold back turbidity had been demonstrated repeatedly in the practice of sanitary engineering in the Pacific islands. The interchange of sodium chloride with calcium carbonates in zeolites is well known. Paul Holmes, civil and sanitary engineer of Ohio, has since suggested that it is possible a like reaction may take place between sodium arsenite and calcium carbonate. Calcium arsenate, which *may* be one end result, is insoluble in water. Research in this direction might prove valuable for soils having a high lime content.

Water Treatment and Equipment

The Sanitary Engineering Section of the Surgeon General's Office in Washington recognized the bacteriological dangers in water in the western Pacific. A recommendation was issued that all water used for troop consumption, and derived from sources situated west of the 180th meridian, be fully treated by coagulation for one hour, then filtered and chlorinated. The fact remained, however, that the equipment necessary to carry out the War Department's recommendations was only partially available at the time of the planning of the campaign. It was hoped that sufficient material would arrive at the staging area or at the target, as the need for it developed. It will be remembered that while the preparation for the Okinawa invasion

was in process, the situation in Europe became extremely critical. National policy gave first priority to the defeat of Germany. Anything needed for Europe necessarily went to that effort, even though the resulting scarcity retarded progress in the Pacific. In the Philippines, the 6th and 8th Army operations, under General MacArthur, were under way and of immediate importance. The result of the struggle at Iwo Jima, scheduled to come before Okinawa, would be pivotal and vital. Supplies had to be given this daring task force. The strain upon shipping and all resources was gigantic. Everyone knew that the Okinawa campaign would make the load colossal. In the face of such a situation, it behooved the 10th Army staff to make every man and piece of equipment count to the utmost. Each officer and man at headquarters, therefore, bent all his efforts toward meeting expected shortages of supplies, materials and men.

One of the best technical men available anywhere was Lt.Col. C. H. Connell (then Major), attached to the staff of the 18th medical general laboratory. Col. Connell, before entering the service, had earned an enviable reputation as professor of engineering chemistry at Texas A. and M. His broad knowledge was freely contributed to the problems of our water supply and his suggestions resulted in the development of a new process for providing treated water with the use of existing Army equipment. The conventional Army apparatus consisted of two 3,000-gal. canvas tanks, a pressure sand filter having a maximum capacity of 15 gpm., a portable gasoline-driven pump in combination with chlorinator and chemical feed unit, plus miscellaneous gasoline-driven centrifugal pumps. Batch treatment for the raw water, using ammoniated alum, soda ash and hypochlorite, is the normal Army method. The floc formed is then settled out in the canvas tanks after which the cleared supernatant fluid in the batch is pumped through the filter, and then to storage or water carts. The War Department had directed that the filtration rate be reduced by one-half, which meant approximately $7\frac{1}{2}$ to 10 gpm. Under the best conditions, using the regular Army method and allowing one hour for sedimentation, only 3,000 gal. of water could be filtered in an eight-hour shift. With the use of two tanks for sedimentation, eliminating storage, production could be increased. Storage for finished water, however, was very essential because trucks were not always available.

The use of ammoniated alum as prescribed by the Army was considered unsatisfactory by the officers engaged in planning for water purification. Standard alum, unadulterated by ammonia was therefore requested and approved for issue. The alum pot was cut out of the circuit and a 5- or 10-gal. metal drum of a known alum solution was substituted. The discharge from the chemical feed unit was connected to a nipple already in place at the bottom of the canvas tank. On the inside, a piece of suction hose was connected to the inlet and laid for a short distance along the circumference. When water was flowing from the hose a gentle swirling motion was imparted to the liquid in the tank. Coagulation and sedimentation took place readily. Tests showed that the incoming water spiraled slowly upward in ever decreasing circles through the sludge blanket. At the center top surface was located a crude weir which was made from a bucket or can. This container served as a clear well out of which wa-

ter was drawn and pumped to the filters. Eosin and chloride tests were made to determine the speed of water passing through the tank. It was discovered that the time ranged from an hour and twenty minutes to two hours when withdrawing water at the rate of 10 gpm. At the 7½-gpm. rate the time was still greater; however, Army pumps could not be relied upon to operate at 7½ gpm., which was the rate recommended by the War Department. The standard practice, therefore, became 10 gpm. The floc formed by the *straight* alum was excellent from the standpoint of density and size of particles. A sludge blanket formed in the tank quickly and the floc carry-over through the basket weir to the filter was no more than normal for such crude equipment. The Army batch method, using the alum pot and the ammoniated alum, meant almost continuous attention to pH and appropriate adjustments to the needle valves controlling the alum input. Each time the clear water was drawn off, nearly 25 per cent of the tank's capacity had to be dumped as unfilterable, which meant losing precious water and time because of the unsettled floc content in the bottom. It often happened that failure to get the right size of particle would require the operator to try again, using a paddle, elbow grease and a bucket of coagulant. Col. Connell's procedure required only infrequent adjustments of the valves, and an occasional pH determination as criteria. It became possible for the equipment to run 24 to 72 hours before draining off the sludge. Furthermore, the continued presence of the coagulated material insured a good floc with less chemical.

Col. Connell agreed that break-point chlorination should be used whenever possible. It was decided that prechlorination should be accomplished as the water entered the coagulation tank. Attempts to carry out this method were successful. Knowing that the bactericidal action of chlorine is maximum at a controlled pH, the decision was made to hold the pH below 7.8. The dosage of chlorine was regulated so as to provide a true residual of not less than 1½ ppm. after the water had passed through both the coagulation tank and filter.

The Engineer Training School on Oahu lent every assistance to the experimentation carried on by Lt. Hallegren, under the direction of Col. Connell. Water from drainage and sewage ditches was used as the raw source. The treated filtrate produced was extremely gratifying from the standpoint of color, turbidity and bacteriology. In a further effort to insure that the water so produced would be harmless to the troops, several officers at the headquarters of the 10th Army voluntarily drank considerable quantities. The desirability of adopting the new method, as tested, was discussed with Gen. Nold, Chief of the Engineering Section, and Col. Westervelt, Chief of the Medical Section, who concurred. A carefully prepared directive was then drawn up and issued to all elements in the entire invasion force. Materials and supplies as recommended were requisitioned and ordered forward to the target. Because of Army regulations it was impossible to order the exclusive use of this new method. It was clear, however, that there were distinct advantages to be gained in emergencies by adopting this process which was christened "the flow-through" method of water purification. In practice this new system was adopted to the exclusion of other Army methods.

DDT in Action

The target was reached early in the morning of April 1. The weather was excellent, the sea calm. Our forces secured the beach with little or no opposition. By 1 P.M., both Yontan and Kadina air fields were being occupied. As a matter of protection it was decided that spraying with DDT should be commenced that afternoon from carrier-based Corsair planes, each plane carrying two belly tanks and two 25-gpm. force pumps. This enabled a plane to discharge approximately 50 gpm. for some six minutes of effective flying time. By 5 o'clock two planes had begun work. Their course carried them directly across the main portions of Bisha-gawa and Nogunu-kainku creeks. On L plus one, two and three, our troops had completed occupation of the middle section of Okinawa from a line east and west through Kamiyama to Tomai on the south, northward to a line east and west through Futsuki. This area, approximately 12 miles in length and varying in width from 3 to 10 miles, represents the best agricultural land on the island. It embraces the portion where the heaviest troop concentration took place at any time. This plateau region is also the principal watershed and from it the majority of the drinking water of the entire island was obtained. About L plus 7, Army C-47's took over the work of spraying and each day, with hardly any interruption save for operational or weather conditions, literally tons of DDT in oil emulsion were dropped. On several occasions the spraying planes passed directly over the top of water purification units. It was natural that the heaviest concentrations of DDT were laid down along water courses, over rice paddies and drainage ditches, which were the insect breeding areas and sources of fresh water. In addition to the DDT that was sprayed by plane, fairly large quantities were liberally dusted and sprayed by hand in the villages, in cane fields and over decomposed flesh where fly breeding had to be controlled. Caves in which dead Japanese were entombed were generously dusted. As severity of the fighting mounted the fly problem became acute, which increased the use of DDT. The lines moved south across Shuri plains, Yonbru valley, Naha, Iwa and on down to the escarpment, and water sources became extremely scarce so that much water had to be taken from shell holes, seepage ditches or wherever found. The concentration of DDT became very high in these water sources, yet no ill effects were reported.

There were estimated to be some 325,000 natives in the compounds by the time the operation had been completed. By far the greater number of these natives drank water which had not been coagulated or filtered. The filthy habits and litter of these people made their village areas and watersheds a reservoir of insect-borne disease which necessitated increased amounts of DDT. Unquestionably these people swallowed considerable quantities of this insecticide with their water, but no ill effects were reported. Soon after the spraying, however, complaints were made of the oily taste of the water.

Japanese Water Systems

The water systems built by the Japanese were primitive indeed. The proximity of the "benjo" (Japanese latrine), pig sty and refuse accumulations suggested no danger to the na-

tives. Their only objective was to obtain water near at hand. Wells and cisterns served the majority. Some wells were dug to depths of over 100 ft. and were usually lined with precast cement pipe set on end, or with 6-in. coral boulders. The inside diameter was not over 30 in. Cisterns were built of concrete pipe similar to that used for well lining or were rectangular concrete structures. They were used to store water from the red clay tile roofs of the village homes. Some towns near the mountains used a few feet of cast-iron pipe, transite pipe or cement and stonework flumes to conduct the flow of seepage springs or mountain brooks to convenient water points. Many times a community water point was provided with a stone and masonry structure which the local Shinto priest dedicated. Here the townsfolk gathered to bathe, wash, gossip and drink the waters. Usually a curb or low wall was built to guard against local storm drainage.

Naha, the principal city, with a population of 60,000, had a water plant and testing laboratory. It served the Navy Yard and the better portions of town through cast-iron mains laid in the streets. The remainder of the population was served by 3,000 primitive wells. Water for the plant was obtained from a collection net of pipe, tapping ten seepage springs which issued from under the raised coral that rested upon an impervious blue clay or marl membrane. This network extended along the west side of the island from Chatan south to Machinato Inlet, a distance of 3,400 yd. The feeder lines were of cast iron and ranged in size from 80 to 100 mm. The collector main became 400 mm. in diameter as it reached the pumping station at Machinato, which was a well-built structure above an underground 100,000-gal. wet well. Unfortunately, all machinery had been removed before capture of the installation. It probably had been diesel-driven pumping equipment of the reciprocating type.

From Machinato to the Naha Water Plant is a distance of 8,000 yd. The water was forced between these points through a 300-mm., cast-iron single-strength line against a vertical head of about 150 ft. The pipe, like the collector line, did not show much tuberculation. It was "pitcast" and jointed by flanged collars. The collector pipe was of conventional bell-and-spigot construction with calked joints. At the plant water was valved directly into a two-pass sedimentation channel with "over-and-under" mixing baffles at the head of the first pass. The channels had a combined flow length of 130 ft. Each channel was roughly 15 ft. wide by 12 ft. deep. At the discharge end the water passed over a weir to a distribution line which conveyed it to one of three sand filters. The filters were about 75 ft. × 75 ft. in plan, with a depth below Plimsoll line of 10 ft. to the top of the sand, and a free board of 2 ft. to the top of the walk-way above. At the point of discharge, which was at the grade line of the sand layer, there was a semi-circular concrete apron of 6 ft. radius. The sand layer, which rested upon common brick underdrains, was so badly calcified and cemented that air hammers were required to uncover the underdrainage system. Water from the sand filters flowed by gravity through a Bailey flow meter to the city, which was 150 ft. below, and across a salt water inlet.

Evidently the sand filters could not be washed back and had ceased to function satisfactorily or else they had insufficient capacity. Whatever the rea-

son, a group of five enclosed pressure filters had been recently installed. Four were 9 ft. in diameter while one was 6 ft. across. The filters received water from the same distribution line that fed the slow sand filters. The plant had been so damaged by our shell fire and bombs that details of construction were difficult to distinguish, but it appeared that water for "wash back" purposes came from a treated supply stored underground but located in the hillside 40 ft. above. Water flowing from these pressure units was stored just below the filters in a small clear well and went onward by gravity toward the city without being metered. This water may have been used for Navy Yard service.

About 2½ miles northeast of Yontan Air Field, a small water installation was in process of construction by the Japanese Army for supplying the Air Field. It consisted of three interconnected circular galleries, 30 ft. from a small mountain stream. All three were about 30 ft. in diameter by 25 ft. in depth. Water was to have been pumped through a cast-iron and transite line varying between 6 and 4 in. in diameter. Some Japanese carboys of liquid hypochlorite were found but no chlorinator was evident nor were the pumps at the site. In the surrounding hills were the general headquarters and barracks for a division. There were also empty gun emplacements and an installation for charging compressed air into torpedoes used by the submarines which docked in a little cove about 1½ miles north. The compressor station was complete with caves to receive the trucks carrying the torpedoes; a two-stage compressor unit gaged for 150 lb. working pressure and air storage tanks with copper tubing to convey the air to the torpedoes on the trucks. The compressors were diesel- or gasoline-driven reciprocating units of a clumsy design, cooled by water.

Okinawa Meets America

The general basic knowledge of hydraulics, such as drainage, gradients, jumps, stilling basins, weirs and dams, was surprising among a people who otherwise were ignorant. No modern well drilling equipment or pumps were seen. Only rarely was there much use of basal water of which there was a considerable quantity. The Ghyben-Hersberg principle was a saving factor at many points in providing basal water to American troops where the Japs had been suffering from lack of water.

The soil mechanics, conservation of soil and contour farming demonstrated by the Okinawans were marvelous to behold. The work spoke eloquently of a thousand years of grueling hand labor, possible only where human toil is the cheapest commodity. In general, the impression was given that poverty, pestilence, storm, heat, famine and drought were the teachers. There was little evidence that the Japanese had taken time to think or reason for the future. Potentially, life on Okinawa could have been modestly comfortable in scenic surroundings and fairly good soil, favored by a tolerable climate.

In the five months from April to September, Okinawa, a principal province of Japan, had been transformed beyond the wildest dream of the Nipponese. The Japanese feudal system disappeared and the Sons of Heaven came to realize the hopelessness of primitive efforts and antiquated ways of life when matched with American power.

The cessation of hostilities with Japan found Okinawa a vast beehive of American activity. Twenty-six air fields, designed to accommodate more than 14,000 planes of every size, had been completed or were in process of completion. Between 400 and 500 miles of graded coral surface roads made a spider's web that brought any part of the island within easy reach of the others. Preparation was being made to feed, house and train 550,000 men. Some 14,000 hospital beds were expected to be ready. Tremendous warehousing and dock facilities were well along toward completion. Utilities, including water works, sewage disposal plants, electric power plants and the myriad other needs of a United States Army, were planned or in progress to care for the enormous invasion forces destined for "Coronet" and "Olympic." Truly, Okinawa was potentially a terrible instrument of power aimed at the heart of Japan. All men are thankful that the storm of war has passed over, leaving Okinawa and the other islands to dream again of peace and hope through the years to come.

Sizing and Installation of Services

By George Roden

Water Dept., St. Paul, Minn.

Presented on Mar. 14, 1946, at the Minnesota Section Meeting, Minneapolis, Minn.

IN determining the size of a required service there are certain fundamental laws of hydraulics that must be considered. It should be borne in mind, for example, that the available pressure must not only produce the desired flow but, in so doing, it must also overcome the frictional loss in the service pipe. In addition to the frictional loss there are losses of head through the meter and plumbing fixtures, as well as through the garden hose. Also to be taken into account are seasonal drops in pressure caused by the heavy drafts during the hot summer days.

By the use of Bernoulli's Theorem and a "slip stick," each individual case can be computed, but such a method is laborious and time-consuming. The St. Paul Water Department has therefore devised for this purpose tables based on essential information gleaned from reliable sources and augmented by department experiments, so that the determination of service sizes has become routine procedure.

Office Procedure

Upon making request for water service, the applicant is referred to the Engineering Division. The applicant may be the contractor, plumber, architect or the owner himself. In any case, he is presumed to have the desired information. The pertinent information is listed on Form 1 (Fig. 1), the total of which indicates the total demand of all fixtures. It is assumed that all fixtures will not be used simultaneously, so that in the case of one family, one third the total demand will suffice for consideration. In this case the probable demand will be 15 gpm.

From information tendered by the applicant, as well as from files of blueprints of streets, the necessary length of connection is determined. In this case there are 20 ft. from main to property line, plus 30 ft. from the property line to the meter, making a total length of 50 ft. Assuming a $\frac{3}{4}$-in. service to be adequate, it will be found by referring to Table 1 that for 100 ft. of $\frac{3}{4}$-in. pipe at 15 gpm. there is a frictional loss of 22 psi. As pressure loss is directly proportional to length, there is, then, for 50 ft. a loss of 11 psi. Reference to the same table shows a loss of head through meters of 4.5 psi., making a total loss of 15.5 psi. From information on card files it is known that the available pressure at the main in this locality is 40 psi. This leaves a residual pressure at the outlet of the meter of 24.5 psi. Assuming that the plumbing fixtures are in accordance with the best plumbing standards, it is known from information on the best practices that 25 psi. at the outlet of meter is adequate.

ST. PAUL WATER DEPARTMENT - ENGINEERING DIVISION

DATA SHEET FOR COMPUTATION OF SIZE OF NEW SERVICE

Date ______ Address ______

Service Size ______ Meter Size ______ Approved by ______

No.	Fixtures	Rate G.P.M.	Total G.P.M.	Demand Calculation
1	Bath	6	6	¾"
1	Wash basin	5	5	L.H. 22 psi. for 100 ft.
1	Laundry	6	6	11 for 50 ft.
1	Kitchen Sink	5	5	L.H. 44.5 thru meter
	Slop Sink	4		15.5
1	3/4" Hose	10	10	40 psi. Available pressure
1	1/2" Shower	6	6	15.5
				24.5 psi. Pressure at outlet of meter
	Shower tubular	10		
	1/2" urinal	4		
	1" "	30		
1	Toilet	5	5	1"
	Flushometer	30		L.H. 7.0 psi for 100 ft.
	Needle bath	30		3.5 50 ft.
				4.5
				8.0
	Total demand		43	40 psi. Available pressure
				8
	1-family	33-1/3%	15	32 psi. Pressure at outlet of meter
	2-family	25%	....	
	3 or 4 family	20%	....	
	Apartments over 4	15%	....	______ Plumber
	Probable demand		15	

Owner ______ Architect ______

Pressure 40 psi. Lot size ______ Service Length 20' Main to property, 30' Property to meter

Premises ______

Architect ______

Plumber ______

Owner ______

Service Size ______ Meter Size ______

Date ______ By ______

This stub to be sent to Application Desk

FIG. 1. Form 1, for Estimating Supply Required

In the case just cited, 24.5 psi. may prove sufficient, but for the sake of illustration let us try a 1-in. connection. Here the frictional loss for 100 ft. is 7 psi., and for 50 ft., 3.5 psi. As the demand charge increases in proportion to the size of meter, the customer is given the benefit of a smaller meter and still uses the ¾-in. meter, making a total loss of 8 psi. and the available pressure at the meter outlet 32 psi. Assuming that the extra outlay for a larger connection is not prohibitive, the 1-in. service would be preferable. Had the applicant resided in a more favorable location in so far as pressure is concerned, a ¾-in. service would have been adequate.

The stub of Form 1 is next forwarded to the application desk where it is placed on file until such time as the plumber requests the connection to be made.

Although more fixtures are involved in office buildings and industries, the procedure is the same. This is a "cut-and-dried" method, but in the case of smaller sizes the engineer passes on so many applications that in most cases he makes the correct assumption at the start.

Costs

Up to and including 1½-in. connections, scheduled prices for various siz[es] connections and widths of streets ar[e] listed in Water Department Regulations. The application clerk prepare[s] an estimate on Form 2 (Fig. 2). This form also embraces an agreement b[y] which the consumer agrees to abide b[y] Water Department Regulations. Fo[r] connections 1½ in. and smaller ther[e] appear on this form the followin[g] charges: (1) schedule charge for installation, (2) frost charge (seasonable), (3) meter setting charge, an[d]

TABLE 1

Approximate Pressure Losses Through Meters and Services
St. Paul Water Department—Engineering Division

Approximate Loss in Head Through Meters *psi.*						Rate of Flow *gpm.*	Approximate Pressure Loss in 100 ft. of Service Pipe *psi.*					
5/8 in.	3/4 in.	1 in.	1 1/4 in.	1 1/2 in.	2 in.		1/2 in.	3/4 in.	1 in.	1 1/4 in.	1 1/2 in.	2 in.
6.0	2.0	0.5	0.5	0.2		10	30.0	11.0	3.0	0.9	0.3	0.1
7.0	2.5	0.7	0.7			11	35.5	13.0	3.5	1.0	0.4	
9.0	3.0	1.0	1.0			12	41.5	15.0	4.5	1.4	0.5	
10.0	3.5	1.2	1.2			13	48.5	17.0	5.5	1.5	0.6	
11.0	4.0	1.5	1.5			14	55.5	19.5	6.0	2.0	0.7	
13.0	4.5	1.7	1.7	0.6	0.2	15	63.0	22.0	7.0	2.1	0.8	0.3
14.0	5.0	2.0	2.0			16	71.0	24.5	7.5	2.3	0.9	
17.0	6.5	2.7	2.5			18		31.0	9.5	3.0	1.1	
22.0	8.0	3.5	3.0	1.0	0.4	20		37.5	11.5	3.7	1.4	0.4
	10.0	4.2	3.5			22		45.0	14.0	4.4	1.8	
	11.0	5.0	4.2			24		53.5	16.5	5.0	2.2	
	19.5	8.0	7.0	2.0	0.9	30			25.5	7.5	3.5	0.9
		11.0	9.0	3.0	1.0	35			37.0	11.5	5.0	1.2
		14.0	12.0	4.0	1.5	40			48.0	14.8	6.5	1.6
		18.0	15.0	5.0	2.0	45				17.8	8.2	2.0
		22.0		6.0	2.5	50				22.0	10.0	2.4
				14.0	5.5	75				45.6	22.4	5.3
				25.0	10.0	100					39.0	9.5

Read down through any size meter and service to see how pressure losses increase with the rate of flow.

Read across through any rate of flow to see how losses decrease with the size of the pipe and meter.

The average 5-room house should be able to draw water at the rate of 12 to 15 gpm.

Safe Maximum Delivery of Meters

Size, *in.*	Flow, *gpm.*
5/8	20
3/4	34
1	53
1 1/2	100
2	160

(4) charge for replacement of pavement.

The first three charges are not subject to adjustment. The work of replacing pavement is performed by the Department of Public Works and charged to the Water Department. This charge may be subject to adjustment. On unpaved streets this charge would not appear. The total of these charges is the payment required before the connection will be authorized. Two-inch and larger services are estimated by the engineering division along the lines indicated on the "Deposit Estimate" (Fig. 3). This estimate is recapitulated on the stub attached to the form and filed at the application desk. Such an estimate appears on Form 2 and is broken down into the following items: (1) frost charge, (2) meter setting charge, (3) cost of installation, (4) rock excavation charge and (5) cost for repaving.

The total of these amounts is the deposit required before the work is authorized. Such an estimate is subject to adjustment and this adjustment is made at the conclusion of the job after the foremen have submitted their job sheets. Besides the aforementioned agreement with reference to connec-

Application Division
Form No. 1A
13-45 2M

STREET CODE	HOUSE NO.	APPLICATION FOR WATER SUPPLY WATER DEPARTMENT CITY OF ST. PAUL, MINN. AUTOMATIC ☐ WATER SUPPLY ☐	APPLICATION NO.

Date____________194___

TO THE BOARD OF WATER COMMISSIONERS,
St. Paul, Minn.

Gentlemen:

I hereby request that the Board cause a____inch water service connection to be laid from the water main on____________Street / Avenue to the property line on Lot______ Block______

Subdivision, ____________

to supply (official number)____________Street / Avenue.

Should the Board lay the service and afford a supply as requested, I hereby agree to assume all responsibility arising from the breakage or leakage of such pipe, and I hereby release said Board and the City of St. Paul from any and all damage caused by water from any breakage or leakage of mains or service pipes.

I also agree to all rules which the Water Board has heretofore adopted or which may be adopted hereafter, from time to time, for the preservation, regulation and protection of the water system of the City of Saint Paul.

Before the service is installed, I also agree to have a stake placed and marked "water service" on the property line where the service is to enter the premises and such pipe shall not be installed under concrete walks, steps or other permanent structures, either installed or contemplated, between the property line and the building to be supplied.

Water to be used to supply____________
(Dwelling, flat, store, factory, etc.)

I agree to pay for this connection in accordance with the final bill rendered and as provided for in the rules, and estimated as follows:

Schedule charge for installation (not subject to adjustment).. $______
Frost Charge.......... ______
*Estimated cost of installation (services over 1½ inches)..... ______
*Add for rock excavation.......... ______
*Estimated cost for repaving.......... ______
Total.......... $______

*This amount is given as estimated cost only and is subject to adjustment on final bill rendered.

____
Owner or Authorized Agent for Owner.

Licensed Plumber____________

Address Owner or Agent____________

Remarks ____________

____
Application Clerk.

Fig. 2. Form 2, for Estimating Cost of Installation

DATE	DEPOSIT ESTIMATE FOR ____SERVICE CONNECTION ____AUTO-FIRE SERVICE	NUMBER

SUPPLY TO____________

SIDE OF STREET____________ IN FROM____________STREET

SIZE	UNIT	ESTIMATED NECESSARY	PRICE	AMOUNT	ACTUAL AMOUNT	
	Cast Iron Pipe					Width of Street
	Smith Pat Sleeve					Kind of Pavement
	Smith Pat Gate					
	Reducer					Width of Pavement
	Bend					
	Gate Box					Size of Main
	Lead and Yarn					
	Ditch {Ordinary / Rock / Frost Charge					Distance Out
	Sidewalk					Service {High Service / Low Service
	Paving					
	Tap and Hauling					Pressure
	Corp. Cock					
	Valve					Number of Apartments
	Tubing					
	Drift					
	Drill Hole					Estimated by
						Estimate Approved Correct
						Installation Approved
	% Overhead					
			TOTAL			

REMARKS AND SKETCH

DATE	DEPOSIT ESTIMATE FOR ____SERVICE CONNECTION ____AUTO-FIRE SERVICE	NUMBER

Supply to____________

Labor and Material______

No. Apts.______ Paving______

Total______

Correct:______ Engineer Approved:______ General Superintendent

Fig. 3. Form 3, for Itemizing Costs of Services

tions, the applicant also signs an agreement defining his obligations with respect to the meter. This concludes the office procedure.

Field Crews for Under 3-in. Connections

Two crews with trucks equipped for the purpose are employed on connections up to and including 2 in. The personnel for each crew consists of one foreman, one skilled worker and from five to twenty laborers, depending on the extent of the work. The skilled worker does the tapping at the main, a function which only Water Department employees are allowed to handle. Each truck is equipped with the tools essential for laying and making connections, the most important being the tapping machine, long extension shovels for tunneling, gate rods, picks and shovels, barricades, etc. Each foreman has a definite part of the city under his jurisdiction, so that in time he becomes thoroughly familiar with soil conditions and the distribution system in his domain. Then he has recourse to up-to-date records of gate valves and pertinent information. If needed, a third crew is used.

The following material is usually involved in the average connection up to and including 1 in.:

- Corporation cock, at the main.
- Curb stop, usually 7 ft. from property line.
- Stop box, adjustable as to height.
- Intervening copper pipe from main to curb stop, curb stop to property line, which is the extent of the department's work.

Should the plumber reach the property line first the Water Department finishes the connection; if the reverse is true the plumber finishes the job. In the first case a mechanical joint is employed, in the second case the plumber wipes the joint. On $1\frac{1}{2}$- and 2-in. connections a gate valve with incidental iron to copper connections is substituted for curb stop. In listing material normal conditions have been assumed and copper pipe is employed. During the war lead pipe was substituted involving makeshifts.

In laying connections, an opening of the desired extent is made at junction with the main and at the junction with the plumber's work at the property line. Additional openings are dug in between, the number depending on the length of the connection. Where soil conditions permit, these openings are connected by borings. With rock and with ground that does not permit such operations an open ditch is employed.

Field Crews for 3-in. and Larger Connections

Three-inch and larger connections find employment for two special crews which cover the entire city. These crews are also employed on emergency work over the entire city, so that the foremen are familiar with conditions at all places. Construction procedure is the same as for the smaller connections, but material is different. Connections at the main are made with Smith Patent sleeve and accompanying gate. On the 3-in. service, a 4-in. valve is used as the 3-in. stem has been found too light for usage. This necessitates the introduction of a 4 × 3-in. reducer at the gate. With this exception the desired size of cast-iron pipe extends from Smith gate to property. In most instances the building sets on property line, so the Water Department brings the connection to the inside of the wall. A gate box is placed over the valve.

The box is equipped with cover for street traffic. The earth formation beneath downtown St. Paul is for the most part sandstone in which the mains are laid in tunnels with lateral drifts for house connections. These laterals are large enough for a man to pass through in a stooping position. In tunnel connections the pipe is brought to the inside of the building through the floor or wall.

For supplies to automatic fire systems the estimate of the size of connection desired is furnished by sprinkler companies, subject to the Department's approval. Meters for services to residences are set inside the building; on connections to industries and larger consumers the meter may be set inside the building or in concrete boxes outside the building. In the latter case the box is placed near the property line, thus insuring the Department against leaks in long connections. Usually the plumber places a spacer in the opening provided for the meter, thus, after the appropriate inspection, the "turn on" crew can turn on water before the meter is placed. This also provides a flushing out of the connection before the meter is placed, a very desirable provision. All meters are owned by the Water Department with the exception of Detector Checks placed on fire line installations. These may be purchased from the Department or, if approved types, from other sources. These checks merely furnish a means of detecting whether water is being used for other than fire protection. In such an event, the check is replaced with fire line meter of an approved type which accurately measures the water consumed.

Distribution System Problems—*Panel Discussion*

By M. E. Driftmier, C. E. Schanze and H. H. Kansteiner

Supt., Munic. Water Works, Burlington, Iowa

Mgr., Joplin Water Works Co., Joplin, Mo.

Mgr., Production & Distr., Water Works Dept., Leavenworth, Kan.

Presented on Oct. 29, 1945, at the Missouri Valley Section Meeting, Kansas City, Mo.

Question 1

What is your plan for extending water mains? Does the utility pay for the extension or do the property owners, by some form of assessment? Are hydrants, valves, services and intersections included in cost? Is the cost based on the size required to serve the consumers benefitted, or on the size required for the good of the distribution system? Who bears the cost of cross-street connections to eliminate dead ends where no customers are directly benefitted?

Burlington: Until May 1943, when the city of Burlington acquired the water company, it was the practice to extend water mains on streets, provided that the revenue received from the prospective consumers would gross 6 per cent on the cost of installation, including valves, hydrants and services to the curb line. If the required revenue was not apparent, the customers were required to provide security guaranteeing the deficit for a ten-year period, after which time the company assumed the deficit on the extension. As a municipal plant, the company is continuing this policy, except that costs are based on a 6-in. main.

The total cost of the extension is paid for by the utility and the customer pays only for his house service from the curb line into his premises.

The cost of cross-street connections is paid for by the utility.

Joplin: The water company has several plans for extending water mains. The first one falls within the Rules and Regulations on file with the Public Service Commission of Missouri.

The company, at its own expense, will make necessary extensions to its distribution system to supply service to prospective customers where the annual revenue to be received from such customers will equal 26 per cent or more of the cost of the required extension, exclusive of service line and meter.

The company will, where domestic service alone is required, install not more than 75 ft. of 2-in. cast-iron cement-lined main to reach one new customer. Where a longer extension is necessary the company will undertake to install, at its own expense, 75 ft. for each prospective customer, provided the customer or customers will agree to pay for, by depositing with the company, the cost of the additional length required over and above 75 ft. for each customer. In such cases the company contracts with the consumer to refund the amount deposited under one of the two following plans:

1. For each additional customer supplied from the main in question a refund to the depositor of three and one-half times the annual revenue received from such additional customer is made.

2. Fifty per cent of the revenue received from additional customers, whose services are connected to the main in question, is refunded annually to the depositor.

Under both plans such refunds cease when the amount of the original deposit has been refunded.

Extensions to provide service to public fire hydrants are made only upon order issued by the city and under conditions set forth in the existing franchise contract.

Joplin has still another plan for extending water mains. This plan covers the installation of 6-in. pipe for fire hydrants, and is a part of the franchise with the city of Joplin.

When the city orders the installation of a fire hydrant, the water works company will do one of two things. Either the fire hydrant branch is connected to an existing main or a maximum of 800 feet of 6-in. pipe is installed at the company's expense to supply the new fire hydrant. The city pays for the cost of installation and the company for the maintenance of fire hydrants.

If less than 800 ft. of 6-in. pipe is necessary for a new fire hydrant installation, the plan with the city works as follows: For example, if the extension required in connection with any particular fire hydrant should be, say, 500 ft., this would give the city a credit of 300 ft., which it could utilize at any future time in ordering other extensions for fire hydrants.

Valves are included in the cost of extension but services are not. All services are installed and maintained at the company's expense. The company's part of the service runs from the main to the curb. The customer installs and maintains the rest of the service. The company also pays for the installation and maintenance of meters.

Leavenworth: The water department pays for the extensions, but requires a guarantee deposit by the customers and property owners to insure the income of the expenditure and extension. The guarantee made, however, is put on deposit and credit of the customer and his water bills are paid out of it for a period of 2 years. The extension then costs the customer very little, and in many cases nothing, depending on the amount deposited. The estimated cost of extension includes connection, hydrants, pavement repairs, excavations and backfill, pipe, valves and fittings on the size of main required for good extensions to the distribution system.

The department sometimes assumes the responsibility and entire costs of eliminating dead ends.

Question 2

What is the minimum pipe size laid on street extension? Is this size based on the requirements for fire protection or just domestic consumption?

Burlington: The minimum pipe size laid for extensions is 6 in. The fire protection requirements are the governing factors in each case. If adequate fire protection is provided, the domestic load is generally taken care of.

Joplin: Two-inch cast-iron cement-lined pipe is the minimum size pipe used for extensions. The 2-in. pipe is for domestic customers. Six-inch pipe is the smallest size now used for fire protection. In the early days of the company, fire hydrants were connected to 4-in. pipe. Many such connections are still in use.

Leavenworth: This depends a great deal on the size of the feeder mains and sizes larger than 6 in. are used where the need seems to be apparent for future extensions.

For fire protection the minimum is 6 in. and an attempt is made to alternate streets with fire protection and small 2-in. size for domestic consumption. Pressures are from 120 to 140 psi.

Question 3

Do you maintain records of the pressures throughout the system? Are these static or residual flow pressures?

Burlington: A record of static pressures throughout the system is maintained; however, static pressures in themselves are of doubtful value unless the residual or flow pressures are also known. Most of the hydrants set back from the curb, and it is therefore difficult to obtain flow pressures without irritating the property owners; yet these are the pressures that show the weak spots.

Joplin: The only record of pressures kept comes from one recording gage at the pumping station and a similar gage in the office, which is about two miles from the pumping station.

Leavenworth: The department does not maintain records of pressures throughout the system but at several points the static pressures are available and this information is supplied to those who need it.

Question 4

What in your opinion is the value of standardization of hydrants, valves, and meters in your distribution system? Do you feel your opinion should be influenced by what equipment you find in service to carry out your predecessor's plan?

Burlington: It is believed that it is a sound policy to standardize on hydrants, valves and meters; however, this policy should not be blindly followed to the extent that improved types are excluded.

Opinion will no doubt be influenced by the makes in service. The use of new types of equipment increases the repair parts inventory and adds to the burden of the maintenance crew; therefore, unless definite benefits are expected from new makes, it is inadvisable to change.

Question 5

How do you control the use of water by other departments for cleaning streets, sewer flushing, etc., to keep the unaccounted-for losses at a minimum?

Burlington: In Burlington, only 7 per cent of the customers are metered and it is therefore impossible to account for the water pumped. The water company receives a milage levy from the city for fire protection and public usage and therefore does not charge the individual city departments.

Question 6

How do you prevent meters in curb settings from freezing?

Burlington: Burlington has been considered "old-fashioned" in that only 7 per cent of its customers are metered; however, there are several hundred metered commercial customers. A 20-in. tile with a double lid cover is used to prevent freezing. During the past 2 years the company has been placing 18 to 24 in. of 6-in. tile in and below the regular tile to obtain additional ground heat. So far, this has worked.

Question 7

What experiences have you had with "Fords" Coppersetters?

Burlington: While the company does not have a great number of Coppersetters, those in service are quite satisfactory.

Question 8

Do you install hydrants with pumper nozzles in addition to the two nozzles? Does your local fire department make sufficient use of the pumper connection to justify the additional expense?

Burlington: Hydrants have been installed with pumper nozzles on new extensions and replacements until about 50 per cent have the pumper. The fire department does not seem to take advantage of the larger volume available at the pumper. It may be that a more flexible hose connection would make their use more general.

Joplin: All fire hydrants have a pumper nozzle in addition to two $2\frac{1}{2}$-in. hose connections. Ludlow fire hydrants with 7-in. standpipe and 6-in. hub for $3\frac{1}{2}$-ft. trench are used.

The fire department makes sufficient use of the large connection to justify the additional expense.

Leavenworth: The department has been following the rule of installing hydrants with pumper nozzles in new locations and replacements everywhere except on old 4-in. pipelines. It is a personal opinion that the fire department makes little use of the pumper connections but that such should be provided for the purpose of maximum service.

Question 9

Does your city allocate special zones in the street for utility extensions, such as water, gas, sewer and others? Do you feel that such a regulation would be workable and beneficial?

Burlington: Our city does not allocate zones for the various utilities, and obviously nothing could be done about the older sections. It is felt that such a policy in presently unimproved streets or new additions would be beneficial.

Joplin: There is no special zone in the street for utility extensions; however, in most cases the water company uses one side of the street and the gas company uses the other side. This plan works out well for both utilities.

The sewer is owned and operated by the city. Most of the sewer pipes are in alleys between streets, and thus out of the way of both gas and water company pipes.

The author believes that a special zone for individual utilities might work, but can see no particular benefit to be derived.

Leavenworth: The water department uses the west side of north and south streets and the north side of east and west streets, which is a good plan to have and follow in most cases. Exceptions might be permitted so long as the rules are not broken down completely.

San Francisco, California—Survival and Retirement Experience With Water Works Facilities

As of December 31, 1940

THE city and county of San Francisco, Calif., are supplied with water through the operations of the Public Utilities Commission. In addition to the San Francisco Water Department, which controls the servicing of water to the customers, as well as certain elements of the supply and transmission works, the Commission also has jurisdiction over the Hetch Hetchy Water Supply and Power System, the San Francisco Municipal Railway, the San Francisco Airport and the Department of Street Lighting. This report covers only partially the works under the supervision of the San Francisco Water Department.

The city of San Francisco is located on the southern horn of the Golden Gate, the entrance to the greatest landlocked harbor in the world, at the mouth of the junction of the Sacramento and San Joaquin valleys. In addition to its commerce and shipping establishments, it has a great variety of important manufacturing industries. California has no coal but hydro-electric plants and crude oil furnish plenty of cheap power to run its industries. The great earthquake of 1906 and the fire which raged over a third of the city in its wake destroyed many of San Francisco's links with the past.

More than 30 years of planning and building and an expenditure of some $100,000,000 were required to bring a water supply from the Hetch Hetchy Valley in the high Sierras more than 160 mi. away. As of June 30, 1940, the system was furnishing approximately 750,000 persons with water, serving over 120,000 consumers with 68.6 mil.gal. daily.

Development of the Existing System

The first works for supplying water to San Francisco's inhabitants were built in 1858 by a private company, the successors of which subsequently developed supplies south of the city and east of San Francisco Bay. The works were built and operated by private companies until the city purchased the system in 1930 and set up the Municipal Water Department as its operating medium under the Department of Public Works, which in 1932 was succeeded by the present Public Utilities Commission. It was under the city's initiative that the Hetch Hetchy supply was developed and completed for use in 1934.

San Francisco's water supply is obtained from local sources in San Mateo and Alameda counties and from the Tuolumne River watershed in the Sierra Nevada Mountains, known as the Hetch Hetchy development. This system is drawn upon to meet the deficiency in the local supplies and to maintain maximum storage in the local reservoirs. In this development the system east of Alameda Creek is under the control of the Hetch Hetchy Water

Supply organization. From Alameda Creek west the aqueduct and other works are operated by the San Francisco Water Department.

The department's supply facilities are divided for operating purposes into the Peninsula and Alameda Divisions. The Peninsula Division includes all territory south of San Francisco and west of the east shore of the bay. The main units of this division are the Upper and Lower Crystal Springs and San Andres and Pilarcitos reservoirs, together with the pipelines, aqueducts, pumps and other facilities for delivery water into San Francisco and to Peninsula consumers.

The main units of the Alameda Division, which include the parts of the system east of the bay, are the Calaveras Reservoir, Pleasonton wells, infiltration galleries at Sunol and required appurtenances for delivery water to the peninsula and for local consumption.

During the annual period noted the local sources produced 31.4 bil.gal. and the Hetch Hetchy system 14.8 bil.gal., making a total of 46.2 bil.gal.

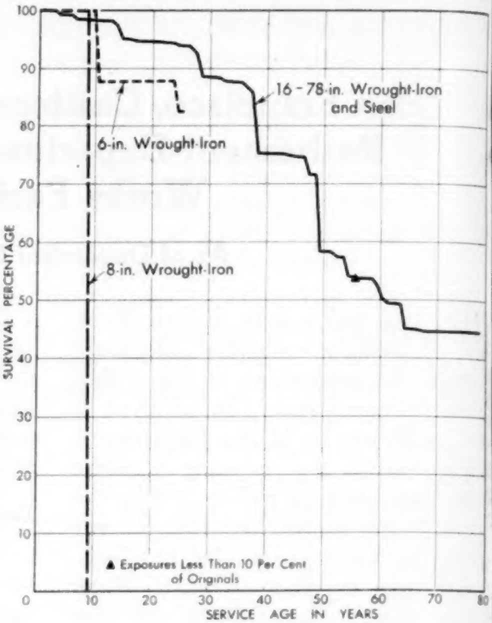

FIG. 1. Mortality Survival Curve—6–78-in. Wrought-Iron and Steel Mains—San Francisco, California

BASE: Feet SURVIVAL: 1862–1940

SIZE *in.*	EXPOSURES *ft.*	RETIREMENTS *ft.*
6	4,604	795
8	1,510	1,510
16–78	1,326,451	257,718

Basis of Study

The information forming the basis of this study was secured from annual reports and other records of the department. The basic data for the facilities included in this report are substantially complete from the beginning of the system's development.

Mortality Survival Study

Mortality studies were made of large wrought-iron, steel and concrete aqueducts and mains only. The records of cast-iron mains in the distribution system installed prior to the time of the earthquake and fire in 1906 are incomplete. Table 1 is a summary of the large mains and Fig. 1 represents the corresponding mortality survival curves determined from the study.

There is also included quite a complete summary of those Class B facilities included in wells, infiltration galleries, tunnels and aqueducts, impounding and distribution reservoirs.

Causes of Retirement

The known causes of retirement of the Class B facilities outlined are included in the accompanying summary.

TABLE 1

SUMMARY OF WROUGHT-IRON, STEEL AND CONCRETE MAINS
SAN FRANCISCO, CALIFORNIA

Size, in.	Kind	No. of Feet Installed	Percentage of Total	No. of Feet Retired	Percentage of Total	No. of Feet in Service	Percentage of Total	Year of First Installation	Average Age, yr.
6	Wrought-iron galvanized	208	0.0	0	0	208	0.0	1929	9.4
6	Wrought-iron bituminous lined and coated	4,396	0.3	795	0.3	3,601	0.3	1915	25.5
8		1,510	0.1	1,510	0.6	0	0	1920	—
12		6,555	0.5	0	0	6,555	0.6	1900	30.1
13		850	0.1	394	0.2	456	0.0	1882	50.5
16		870	0.1	870	0.3	0	0	1895	—
18		4,475	0.3	4,475	1.7	0	0	1887	—
22		63,652	4.7	32,529	12.5	31,123	2.8	1862	53.5
23		6,215	0.5	72	0.0	6,143	0.6	1891	49.5
30		247,468	18.1	122,735	47.2	124,733	11.3	1863	41.2
33		2,409	0.2	0	0	2,409	0.2	1885	55.5
36		149,899	11.0	68,267	26.3	81,632	7.4	1885	49.7
37		14,300	1.0	2,425	0.9	11,875	1.1	1885	51.4
44		133,824	9.8	11,546	4.4	122,278	11.0	1885	52.1
54		17,115	1.2	0	0	17,115	1.5	1891	36.8
10	Steel bituminous lined and coated	9,580	0.7	0	0	9,580	0.9	1938	2.5
16		40,353	2.9	13,976	5.4	26,377	2.4	1888	14.4
20		65,728	4.8	0	0	65,728	5.9	1926	9.2
22		13,740	1.0	0	0	13,740	1.2	1902	38.3
23½		9,516	0.7	429	0.2	9,087	0.8	1923	17.4
24		26,443	1.9	0	0	26,443	2.4	1926	8.5
28		7,480	0.5	0	0	7,480	0.7	1936	4.5
30		18,561	1.4	0	0	18,561	1.7	1915	10.9
36		69,651	5.1	0	0	69,651	6.3	1924	5.2
44		56,592	4.1	0	0	56,592	5.1	1924	9.1
48		12,354	0.9	0	0	12,354	1.1	1931	9.4
54		73,873	5.4	0	0	73,873	6.7	1928	10.9
60		191,545	14.0	0	0	191,545	17.4	1925	9.8
66		78,896	5.8	0	0	78,896	7.1	1935	5.5
76		3,858	0.3	0	0	3,858	0.3	1935	5.5
78		649	0.0	0	0	649	0.0	1937	3.5
57	Concrete	6,822	0.5	0	0	6,822	0.6	1933	7.5
62		26,014	1.9	0	0	26,014	2.3	1935	5.5
69		3,087	0.2	0	0	3,087	0.3	1934	6.5
TOTAL		1,368,488	100.0	260,023	100.0	1,108,465	100.0		23.1
Percentage of Total		100.00		19.00		81.00			
Average Size, *in.*		40.1		30.0		42.5			

TABLE 1 (contd.)

Mortality Survival Ratios

Size, *in.*	Kind	No. of Feet	Period Covered, *yr.*	Percentage
6	Wrought-iron	4,604	25.5	82.323
8	Wrought-iron	1,510	20.5	0
10 and 12	Wrought-iron and steel	16,135	40.5	100.000
Over 12	Wrought-iron and steel	1,310,316	78.5	44.415
57–69	Concrete	35,923	7.5	100.000
TOTAL		1,368,488		

Acknowledgment

The collection and compilation of data pertaining to the study in San Francisco were under the general supervision of N. A. Eckart, General Manager and Chief Engineer of the San Francisco Water Department and a member of the Committee on Survival and Retirement Experience With Water Works Facilities.

SUMMARY OF CLASS B FACILITIES
SAN FRANCISCO, CALIFORNIA

Wells

Pleasonton Field

Bored Wells: 10 in. in diameter, wrought-iron cased, 50–196 ft. deep; some artesian, some deep well pumps and some air lift.

Nos. F1, F8, F15, F22—Installed in 1900 and not used because other wells were better.

No. F28—Installed in 1900 and retired in 1930 because other wells were better.

Nos. C1 and C1X—Installed in 1898; no good and not used.

Nos. C2 to C5, C5½, C6 to C14, C16, C19 to C22—Installed in 1898; became standby in 1934 when new supply developed.

Nos. C15, C17, C19½, C22½, C23 to C25, C23½, C24½, C25½—Installed in 1901; became standby in 1934 when new supply developed.

No. C18—Installed in 1898 and retired in 1926 because of collapse.

Nos. C20½, C21½, C27, C28—Installed in 1901 and retired in 1926; no reason given.

Nos. A1, A2, A11, A13, A14, A15, A16, B1—Installed in 1898 and retired in 1909 because of change in collecting system. A14 in use by others in 1926.

Nos. D1, D2, D4, D6, D8, E1 to E7, E10, E16, I2, I6, I4—Installed in 1898 and retired in 1904 because other wells were better.

No. G39—Installed in 1898 and retired prior to 1911; no reason given.

Nos. G7, G10, G29, G37—Installed in 1898 and retired in 1930 because other wells were better.

No. G13—Installed in 1898 and retired in 1924 when replaced with new well.

No. G19—Installed in 1898 and retired in 1926; no reason given.

Nos. G14–M10—Installed in 1900 and retired prior to 1913; no reason given.

No. G1—Installed in 1898 and retired prior to 1926; no reason given.

Nos. H1, H7—Installed in 1898 and retired prior to 1912; no reason given. In use by others after.

No. H25—Installed in 1900 and retired prior to 1911; no reason given.

Nos. M20, M5, L21, M15—Installed in 1900 and retired prior to 1926; no reason given.

Nos. A3 to A7, A9—Installed prior to 1903 and retired about 1909 because of change in collecting system.

Nos. B3, B5—Installed prior to 1904 and retired about 1909 because of change in collecting system.

No. H14—Installed prior to 1904 and retired prior to 1912; no reason given.

Nos. N1, N3, N5, N7, N9, N12, G43, G42, G44, G46, G49, G51—Installed prior to 1904 and retired in 1930 because other wells were better.

No. G40—Installed prior to 1904 and retired in 1926; no reason given.

No. G45—Installed prior to 1904 and retired prior to 1913; no reason given.

Bored Wells: 12 and 10 in. in diameter, wrought-iron cased, 135 to 385 ft. deep; deep well or air lift.

Nos. G35, G36, G41, G33, G14 new, G38½, G34—Installed in 1924 and retired in 1930 because other wells were better.

Nos. M22½, M25—Installed in 1920 and became standby in 1934 when new supply developed.

No. G13 new—Installed in 1924 and became standby in 1934 when new supply developed.

No. M19½—Installed in 1920 and retired prior to 1926; no reason given.

Nos. M33, M36—Installed in 1916 and retired prior to 1926; no reason given.

Nos. C26¼, 26½, 27½, 28½—Installed in 1924 and retired prior to 1926; no reason given.

Almeda—Installed in 1919 and retired in 1930 because other wells were better.

Gravel Pack Wells: 14-in. stove pipe casing, 26-in. gravel, 221 to 734 ft. deep; deep well turbines.

Nos. O1, O12, O3, O6, O9, G22, M19¼—Installed in 1924; deepened in 1931; became standby in 1934 when new supply developed.

Nos. G38, G6¾—Installed in 1931 and became standby in 1934 after new supply developed.

Nos. C21¾, F16—Installed in 1926 and became standby in 1934 when new source developed.

No. F19—Same except installed in 1925.

No. F22½—Same except installed in 1924.

Nos. F24¾, F27½, G32¾, G43¼—Same except installed in 1930.

No. G25—Installed in 1924 and retired prior to 1930 because of sanding.

Nos. M10 new, M5 new—Installed in 1924; deepened in 1931 and became standby in 1934 when new supply developed.

No. M15 new—Installed in 1924 and became standby in 1934 when new source developed.

Sunset Field

Gravel Pack Wells: Inner casing 10 to 14 in., outer casing 16 to 20 in., 155 to 270 ft. deep; deep well turbines.

No. 1—Installed in 1931 and retired in 1935 when new source developed.

No. 2—Installed in 1931 and abandoned in 1931 because of freezing.

Nos. 3 and 4 and 21—Installed in 1931 and retired in 1935 when new source developed.

Nos. 5 to 10, and 13 to 20—Installed in 1930 and retired in 1935 when new source developed.

No. 620—Installed in 1915 and retired in 1935 when new source developed.

No. 630—Installed in 1915 and retired in 1930 because of corrosion.

Test 7-in. Drilled Well, 200 ft. deep—Installed in 1931 and retired in 1935.

Leland Avenue No. 1

No details; constructed by realty company prior to 1909 and retired in 1927 because of sanding.

Leland Avenue No. 2

Gravel Pack Well, 16- and 24-in. diameter, 150 ft. deep. Constructed in 1915 and retired in 1933 when cheaper source developed.

Potters Wells

Installed in 1871 and abandoned in 1886. Cost $10,400. No details available.

Warren and Tuttle Wells

Installed in 1883 and abandoned in 1886. Cost $10,400. No details available.

Ringold Artesian Wells

Abandoned in 1882. No further details available.

Pilarcitos Artesian Wells

Installed in 1864–65–69 and 1871. All abandoned upon completion; no results.

Lobos Creek Artesian Well

Installed in 1869 and immediately abandoned; no results, and possible lawsuits.

Lobos Creek, Lake Street

Installed in 1901 and abandoned in 1901 because of pollution.

Richmond Nos. 617 and 628

10- to 14-in. drilled wells, 211 and 307 ft. deep; emergency use. Constructed in 1915 and retired in 1924. Cleaned out and pump installed in 1934.

Richmond No. 616

Same, except retired in 1915 because of insufficient yield.

Ravenswood Wells

Total number 49, 7- and 10-in. bored and cased wells; 6 drilled in 1901, rest in 1905. Retired in 1905 because of threatened lawsuits.

Hadsell Field Nos. 1, 2 and 3

12-in. drilled wells 96 to 285 ft. deep; drilled in 1912 and probably never used.

Sunol Valley Wells

Nine or ten shallow wells 15 to 20 ft. deep. Dug in 1901; no details given.

Sunol Valley Concrete Well

Dug well 5 ft. in diameter, 20 ft. deep. Installed in 1901 and retired in 1930; no details given.

Impounding Reservoirs

Upper Pilarcitos—Earth embankment dam across Pilarcitos Creek, 210 ft. long, 36 ft. maximum height; impounding 60 mil.gal.; safe yield 2 mgd. Constructed in 1862 and retired in 1868 because of insufficient capacity, submergence in larger reservoir.

Pilarcitos—Earth embankment dam across Pilarcitos Creek, 520 ft. long, 95 ft. maximum height; impounding 1,000 mil.gal. from natural drainage area of 3.8 sq.mi. and by partial diversion from 1.4 sq.mi. Constructed in 1866, raised 25 ft. in 1874, and still in service.

San Andres—Earth embankment dam across San Andres Creek, 950 ft. long, 105 ft. maximum height; impounding 6,000 mil.gal. from natural drainage area of 4.4 sq.mi. and by partial diversion from 9.2 sq.mi. Safe yield with Pilarcitos of 7 mgd. Constructed in 1870, raised 16 ft. in 1875 and 10 ft. in 1928, and still in service.

Upper Crystal Springs—Earth embankment dam across Laguna Creek, 520 ft. long, 92.5 ft. maximum height, impounding 9,426 mil.gal. from natural drainage area of 9 sq.mi. Constructed in 1877 and retired in 1890 because of insufficient capacity, submergence in larger reservoir. Salvage $156,000; used as highway.

Lower Crystal Springs—Arched gravity concrete dam across San Mateo Creek, 600 ft. long, 154 ft. maximum height, impounding 22,500 mil.gal. from natural drainage area of 22.5 sq.mi. part diverted to San Andres; safe yield 9 mgd. Constructed in 1888, raised in 1890 and 1911, and still in service.

Calaveras—Earth embankment, part hydraulic fill dam across Calaveras Creek, 1,200 ft. long, 220 ft. maximum height, impounding 31,800 mil.gal. from natural drainage area of 100 sq.mi. and by partial diversion from 35 sq.mi.; safe yield 30 mgd. Constructed in 1925 and still in service.

Infiltration Galleries

Sunol—Concrete, cut and cover, gallery, 3 by 5 ft. to 7 by 10.5 ft., 896 ft. long with 6,050 1¼- to 1¾-in. inlet pipes with brass strainers. Constructed in 1900 and still in service.

Sunol—Timber, cut and cover, gallery, 8 by 10 ft., 1,180 ft. long. Constructed in 1901 and still in service.

Sunol—Perforated concrete pipe gallery in creek channel, 30-in. diameter, 433 ft. long. Constructed in 1917 and still in service.

Sunol—Perforated concrete pipe gallery in creek channel, 30-in. diameter, 1,300 ft. long. Constructed in 1918 and still in service.

Sunol—Similar gallery, 1,000 ft. long. Constructed in 1926 and still in service.

Tunnels and Aqueducts

Lobos Creek Aqueduct

Flume—Lobos Creek to Fort Point—Rectangular covered redwood flume for transmission, 1.6 by 1.9 ft., 12,016 ft. long. Constructed in 1858 and retired in 1893 because of slides and excessive maintenance.

Flume at Fort Point—Rectangular covered redwood flume for transmission, 1.6 by 1.9 ft., 500 ft. long. Constructed in 1858 and retired in 1870 because of slides; replaced by tunnel.

Flume, Fort Point to Black Point—Rectangular covered redwood flume for transmission, 1.6 by 1.9 ft., 12,100 ft. long. Constructed in 1858 and retired in 1862 because of slides and excessive maintenance; replaced by cement pipe and tunnels.

Tunnel—Fort Point—Probably brick-lined tunnel, 3.5 by 3.5 ft., 300 ft. long. Constructed about 1870 and retired in 1870 because of retirement of connecting flumes.

Tunnel—Black Point—Brick-lined tunnel, 2.5 by 4.5 ft., 2,800 ft. long. Constructed in 1862 and retired in 1893 because of retirement of connecting flumes.

Cement Pipe—Cement pipe aqueduct, 2.2 ft. inside diameter, 8,589 ft. long. Constructed in 1862 and retired in 1893 because of retirement of connecting flumes.

Islaid Creek Aqueduct

Flume — Rectangular covered redwood flume, 1 by 1 ft., 14,000 ft. long. Constructed in 1861 and retired in 1873 because of abandonment of supply.

Original Pilarcitos Aqueduct

Tunnel No. 1—Timber tunnel housing 30-in. pipe, 3.5 by 5.1 ft., 1,495 ft. long. Constructed in 1861, brick lining and pipe removed in 1871; now in present Pilarcitos Aqueduct. Pipe in tunnel riveted sheet iron 2.5-ft. diameter. Installed in 1862; pipe salvaged in 1871.

Flume — Rectangular covered redwood flume, 1.3 by 2.5 ft., 143,000 ft. long. Constructed in 1862 and retired in 1868 because

of insufficient capacity and excessive maintenance.

Pilarcitos Aqueduct

Flume (*Sec. 2*)—Rectangular covered redwood flume, 2.0 by 3.6 ft., 298 ft. long. Constructed in 1868, rebuilt in 1880 and 1898 and retired in 1941, because of excessive maintenance; replaced with concrete pipe.

Tunnel No. 2 (*Sec. 3*)—Brick lined, oval shape, 3.5 by 5.1 ft., 3,426 ft. long. Constructed in 1868.

Flume (*Sec. 4*)—Rectangular covered redwood flume, 1.9 by 3.5 ft., 325 ft. long. Constructed in 1868, replaced in 1897 by pipe because of excessive maintenance.

Pipe (*Sec. 4*)—44-in. wrought-iron pipe, inverted siphon, 730 ft. long. Installed in 1897.

Flume (*Sec. 5*)—Rectangular covered redwood flume, 1.9 by 3.5 ft., 2,674 ft. long. Constructed in 1868, rebuilt in 1902 and replaced with pipe in 1936 because of excessive maintenance.

Pipe (*Secs. 6, 8, 10*)—22-in. wrought-iron pipe in siphon and outlet, 4,488 ft. long. Constructed in 1887 and retired in 1936 because of deterioration.

Flume (*Secs. 7, 9*)—Rectangular covered redwood flume, 1.9 by 3.5 ft., 2,310 ft. long. Constructed in 1887, rebuilt in 1904 and replaced with pipe in 1936 because of excessive maintenance.

Pilarcitos Main, Side Flume

Rectangular covered redwood flume, 1.2 by 1.5 to 1.3 by 3.5 ft., 10,000 ft. long. Constructed in 1866, raised in 1867 and 1868, rebuilt in 1877, 5,000 ft. rebuilt in 1910.

Pilarcitos Pipe Line, Flume and Tunnels

Greenhouse Flume—Rectangular covered redwood flume, 3.7 by 3.2 ft., 5,255 ft. long. Constructed in 1868, rebuilt in 1905, 3,000 ft. retired in 1914, 1,455 ft. in 1926.

Lake Honda Tunnel—Brick-lined, oval-shaped tunnel, 3 by 4.3 ft., 2,820 ft. long. Constructed in 1868.

Lakeview Tunnel—Pressure tunnel, 36-in. steel pipe backed with concrete, 784 ft. long. Constructed in 1934.

Bald Hill Tunnel—Brick-lined, oval-shaped tunnel, 3 by 4.7 ft., 2,820 ft. long; reservoir outlet. Constructed in 1870.

North S.A. Outlet Tunnel—Concrete-lined, horseshoe-shaped tunnel, 8 by 8 ft., 718 ft. long; reservoir outlet. Constructed in 1928.

Locks Creek Aqueduct

Flume — Rectangular covered redwood flume, 1 by 1.2 to 1.5 by 2.5 ft., 41,650 ft. long, diversion flume. Constructed in 1871 and retired in 1898 because of slides, accidents, fires, excessive maintenance and small supply.

Pipe—22-in. wrought-iron pipe, 11,902 ft. long, diversion. Constructed in 1871 and retired in 1898 because of abandonment of flume.

Stone Dam Aqueduct

Flumes — Rectangular covered redwood flumes, 2.5 by 5 to 4 by 5 ft., 30,995 ft. long, diversion purpose. Constructed in 1871, 26,715 ft. abandoned in 1898 because of deterioration. New structure relocated and shortened by tunnel.

Tunnel No. 1—Brick-lined, oval-shaped tunnel, 3.5 by 4.5 ft., 3,202 ft. long. Constructed in 1871.

Pipe—37½-in. wrought-iron, 3,718 ft. long. Constructed in 1871 and retired in 1898 when relocated.

Flume — Rectangular covered redwood flumes, 3 by 5 to 4 by 6 ft., 13,808 ft. long. Constructed in 1898, 2,905 ft. replaced in 1937, 10,903 ft. in 1938, 2,905 ft. replaced with concrete pipe.

Tunnel No. 2—Concrete-lined tunnel, 4.3 by 4.3 ft., 3,530 ft. long. Constructed in 1898.

Pipe Siphon—44-in. wrought-iron, 2,109 ft. long. Constructed in 1898 and replaced in 1936.

Pipe Siphon—44-in. steel, 2,106 ft. long. Constructed in 1936.

Concrete Pipe—48-in. diameter, 2,905 ft. long. Constructed in 1937.

Crystal Springs Pump Aqueduct

Flume — Rectangular covered redwood flume, 4 by 5 ft., 29,294 ft. long. Constructed in 1898 and 1903 and replaced with canal in 1932, because of excessive maintenance and limited capacity.

Canal—Gunite-lined canal, 3 to 11 ft. wide, 3.75 ft. deep, 30,200 ft. long. Constructed in 1932, hipped redwood roof added in 1934.

S.A. Tunnel—Concrete-lined tunnel, 5.25 by 6 ft., 412 ft. long. Constructed in 1898.

S.A. Siphon—6-ft. diameter concrete pipe, 603 ft. long. Constructed in 1934.

Outlet No. 1—Brick-lined tunnel, 7.5 by 7.5 ft., 358 ft. long. Constructed in 1891.

Outlet No. 2—Concrete-lined tunnel, 9 by 10 ft., 640 ft. long. Constructed in 1936.

Crystal Springs Pipeline No. 1 Tunnels

Brisbane Tunnel—Circular pressure tunnel, 44-in. wrought-iron pipe, backed with brick, 301 ft. long. Constructed in 1885.

City Tunnel—Brick-lined, horseshoe tunnel, 5.75 by 6.5 ft., 2,144 ft. long. Constructed in 1885.

Sierra Point Tunnel—Concrete-lined horseshoe tunnel, 7 by 7 ft., 400 ft. long. Constructed in 1928 and retired in 1929 because of damage by highway cut below.

Crystal Springs Pipeline No. 2 Tunnels

Tunnel No. 1—Pressure tunnel, 60-in. steel pipe, backed with concrete, 1,427 ft. long. Constructed in 1936.

Tunnel No. 2—Same as No. 1 except 334 ft. long.

Tunnel No. 3—Same as No. 1 except 2,285 ft. long.

Davis Tunnel

Rectangular, concrete-lined, diversion tunnel, 4.33 by 4.75 ft., 1,205 ft. long. Constructed in 1898.

Bernal Tunnels

Two circular pressure tunnels, 44-in. wrought-iron pipes, backed with brick, 225 and 1,120 ft. long; distribution works. Constructed in 1885.

Lake Honda System Tunnels

Upper Outlet Tunnel—60-in. circular outlet tunnel, concrete or brick-lined, 188 ft. long. Constructed in 1897.

Lower Outlet Tunnel—Egg-shaped, concrete-lined distribution tunnel, 4 by 5 ft., 750 ft. long. Constructed in 1864.

7th Avenue Tunnel—Horseshoe-shaped, concrete-lined distribution tunnel, 5.5 by 6 ft., 510 ft. long. Constructed in 1896.

Sewer Tunnel—Oval, concrete-lined drainage tunnel, 5 by 6 ft., 640 ft. long. Constructed in 1901 and retired in 1916 when drainage system changed.

Lake Merced Drainage System

L.M. Tunnel—Oval brick-lined tunnel, 5.5 by 8.5 ft., 3,036 ft. long. Constructed in 1897.

Colma Canal—Brick-lined canal, 10 by 7 ft., 3,840 ft. long. Constructed in 1897.

Drainage Ditch—Earth ditch, unlined, 3 by 3 ft., 2,562 ft. long. Constructed in 1901.

Vista Grande Flume—Rectangular redwood flume, 3 by 3 ft., 6,198 ft. long. Constructed in 1897.

Vista Grande Canal—Brick and concrete-lined canal, 5 by 5 ft., 1,650 ft. long. Constructed in 1897 and retired about 1920.

Abbey Flume—No detail given. Constructed in 1869, rebuilt in 1885 and retired in 1904.

Niles Aqueduct

Masonry Aqueduct—Rubble bottom and walls, arched brick top, 3 by 5 ft., 2,760 ft. long. Constructed in 1888 and retired in 1930 because of system changes.

Flume — Rectangular covered redwood flume, 4 by 3 ft., 3,200 ft. long. Constructed in 1888, rebuilt in 1904 and retired in 1927 and 1930 because of deterioration and system changes.

Pipe—36-in. wrought-iron pipe, 5,611 ft. long. Constructed in 1888, 312 ft. retired in 1917 and balance about 1937 because of deterioration and system changes.

Pipe—14-in. wrought-iron pipe, 312 ft. long. Constructed in 1917 and retired in 1937 because of system changes.

Concrete Pipe—20-in. concrete, 400 ft. long. Constructed in 1927 and retired in 1930 because of system changes.

Laguna Creek

Ditch—Unlined earth canal, 6 to 20 ft. wide, 6 ft. deep, 1,300 ft. long. Constructed in 1901 and replaced with pipeline in 1909.

Tunnel—Rectangular concrete-lined tunnel, 4.2 ft. by 4.3 ft., 354 ft. long. Constructed in 1901.

Sunol Aqueduct

Tunnels Nos. 1, 3, 4, 5—Rectangular concrete tunnels, 5 by 5.5 ft., 13,707 ft. long. Constructed in 1900.

Tunnel No. 2—(Orig.) same, 394 ft. long. Constructed in 1900 and retired in 1908, in right of way sold to W.P.R.R., replaced at no cost to water company.

Tunnel No. 2 (pres.)—Rectangular concrete tunnel, 6 by 5.67 ft., 856 ft. long. Constructed in 1908.

Flume (4 sect.)—Rectangular covered redwood flumes, 6 by 3.5 ft., 11,922 ft. long. Constructed in 1900 and removed in 1908 and 1923 because of excessive maintenance.

Concrete Aqueduct—Rectangular concrete aqueduct, 5.5 ft. by 5.67 ft., 11,635 ft. long. Constructed in 1923.

Upper Alameda Tunnel

Horseshoe-shaped concrete-lined diversion tunnel, 5.5 by 6.5 ft., 9,709 ft. long. Constructed in 1932.

Calaveras Outlet

Horseshoe-shaped, concrete-lined outlet tunnel, 8 by 8 ft., 1,519 ft. long. Constructed in 1926.

Calaveras Pipeline Tunnel

Similar to above, 1,075 ft. long. Constructed in 1934.

H. H. Irvington Tunnel

Horseshoe-shaped, concrete-lined tunnel, 10.5 ft. by 10.5 ft., 18,192 ft. long. Constructed in 1934.

H. H. Pulgas Tunnel

Horseshoe-shaped, concrete-lined tunnel, 10.25 by 10.25 ft., 9,007 ft. long. Constructed in 1926.

H. H. Pulgas Tunnel Outfall Canal

Reinforced concrete-lined canal, 9 ft. wide, 12 to 3.5 ft. deep, 946 ft. long. Constructed in 1926.

Distribution Reservoirs

Sunset (North Basin)—Cut and fill, concrete-lined and covered basin, 600 by 1,000 ft. maximum area, 29.5 ft. deep, 89.4-mil.gal. capacity. Constructed in 1938 and still in service.

University Mound (South Basin)—Cut and fill, concrete-lined and covered basin, 745 ft. by 765 ft. maximum area, 25.3 ft. deep, 81.5-mil.gal. capacity. Constructed in 1937 and still in service.

University Mound (North Basin)—Cut and fill, concrete-lined open basin, 625 by 780 ft. maximum area, 26.5 ft. deep, 59.4-mil.gal. capacity. Constructed in 1885, raised 6 ft. in 1924 and still in service.

Merced Manor—Cut and fill, concrete-lined and covered basin, 265 by 350 ft. maximum area, 22 ft. deep, 9.5-mil.gal. capacity. Constructed in 1936 and still in service.

Lake Honda—Concrete dam in creek, excavated basin, concrete-lined, open, 320 by 1,265 ft. in area, 35 ft. deep, 44-mil.gal. capacity. Constructed in 1861, raised 6 ft. in 1915 and still in service.

College Hill—Cut and fill, clay and rubble masonry lined, open basin, 360 by 430 ft. in area, 16.5 ft. deep, 13.5-mil.gal. capacity. Constructed in 1870 and still in service.

Francisco Street—Cut and fill, brick-lined, partly covered with wood, 190 by 440 ft. in area, 8 ft. deep, 2.5-mil.gal. capacity. Constructed in 1861, roof added in 1863, rebuilt in 1879 and 1919 and still in service.

Lake Merced—Natural lake increased by two earth dams, open, 2,000 by 15,000 ft. in area, 30 ft. deep, 2,500-mil.gal. capacity. Constructed in 1895, drainage added in 1897–1901 and still in service for emergency storage.

Lombard Street—Cut and fill, brick-lined, open basin, 185 ft. square, 18 ft. deep, 2.7-mil.gal. capacity. Constructed in 1861, roof added in 1862, replaced in 1882, burned off in fire of 1906 and still in service.

Potrero Heights—Circular, rock cut basin, brick- and cement-lined, covered, 120 ft. diameter at top, 22 ft. deep, 1-mil.gal. capacity. Constructed in 1897, wood roof added in 1932 and still in service.

Stanford Heights—Cut and fill, concrete-lined, wood-covered, partitioned basin, about 175 by 525 ft. in area, 20 ft. deep, 11-mil.gal. capacity. West basin constructed in 1923, east basin in 1928 and still in service.

Wilde Avenue—Cut and fill, concrete-lined, wood-covered basin, irregular shaped, 6,150-sq.ft. area, 10 ft. deep, 0.5-mil.gal. capacity. Constructed in 1902, gunited in 1933 and still in service.

Market Street—Basin cut in rock, masonry walls, open, approximately 100 by 200 ft. in area, 15 ft. deep, 2.25-mil.gal. capacity. Constructed in 1862, retired in 1879 because of operating changes, and street cut through.

Brannan Street—Basin cut in rock, brick-lined, open, 80 by 100 ft. in area, 8 ft. deep, 0.4-mil.gal. capacity. Constructed in 1862, retired in 1883 when elevation low and source of supply abandoned.

Original Clay Street—Rectangular, probably redwood basin, no details except 0.1-mil.gal. capacity. Constructed about 1864 and retired about 1874.

Clay Street, 2nd—Redwood basin, about 35 by 60 ft. in area, 9 ft. deep, 0.14-mil.gal. capacity. Constructed in 1874 and retired in 1885 when replaced by larger steel tank.

Clay Street Tank—Circular, wrought-iron, wood-covered tank, 60-ft. diameter, 11 ft. deep, 0.25-mil.gal. capacity. Constructed in 1885, roof burned in 1906 and replaced; still in service.

Clarendon Heights Tank—Circular, wrought-iron, wood-covered tank, 80-ft. diameter, 15 ft. deep, 0.5-mil.gal. capacity. Constructed in 1895 and still in service.

Presidio Heights Tank—Circular, covered steel tank, 60-ft. diameter, 34 ft. deep, 0.7-mil.gal. capacity. Constructed in 1903 and still in service.

Lincoln Park Tank—Circular, covered concrete tank, 26-ft. diameter, 20 ft. deep, 0.08-mil.gal. capacity. Constructed in 1924 and still in service.

Forest Hill Tank—Circular, covered steel tank, 45-ft. diameter, 26 ft. deep, 0.3-mil.gal. capacity. Constructed in 1927 and still in service.

Sunset Tank—Circular, covered concrete tank, 80-ft. diameter, 15 ft. deep, 0.5-mil.gal. capacity. Constructed in 1930, not retired but out of service since Sunset Wells shut down in 1935.

Summary of Installations and Retirements San Francisco, California

Mains

6-in. Wrought-Iron Galvanized Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1929	154	154	0
1937	54	54	0
1940	0	0	0
Total	208	208	0

6-in. Wrought-Iron Bituminous-Lined and Coated Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1915	4,396	3,601	795
1940	0	0	0
Total	4,396	3,601	795

Retirements by Years

Year Installed	*Feet*	*Year*	*Feet*	*Year*
1915	564	1925	231	1939

8-in. Wrought-Iron Bituminous-Lined and Coated Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1920	1,510	0	1,510
1940	0	0	0
Total	1,510	0	1,510

Retirements by Years

Year Installed	*Feet*	*Year*
1920	1,510	1929

12-in. Wrought-Iron Bituminous-Lined and Coated Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1900	1,670	1,670	0
1914	4,885	4,885	0
1940	0	0	0
Total	6,555	6,555	0

13-in. Wrought-Iron Bituminous-Lined and Coated Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1882	394	0	394
1890	456	456	0
1940	0	0	0
Total	850	456	394

Retirements by Years

Year Installed	*Feet*	*Year*	*Feet*	*Year*
1882	38	1906	356	1926

16-in. Wrought-Iron Bituminous-Lined and Coated Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1895	870	0	870
1940	0	0	0
Total	870	0	870

Retirements by Years

Year Installed	*Feet*	*Year*
1895	870	1928

18-in. Wrought-Iron Bituminous-Lined and Coated Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1887	2,646	0	2,646
1907	1,829	0	1,829
1940	0	0	0
Total	4,475	0	4,475

Retirements by Years

Year Installed	*Feet*	*Year*
1887	2,646	1898
1907	1,829	1928

22-in. Wrought-Iron Bituminous-Lined and Coated Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1862	6,600	0	6,600
1863	2,998	0	2,998
1875	13,722	10,134	3,588
1877	16,000	0	16,000
1882	6,828	6,312	516
1884	4,200	4,200	0
1892	2,500	0	2,500
1895	6,991	6,664	327
1913	966	966	0
1914	692	692	0
1919	2,155	2,155	0
1940	0	0	0
Total	63,652	31,123	32,529

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1862	6,600	1868				
1863	2,035	1895	963	1926		
1875	422	1906	623	1907	1,903	1935
	640	1936				
1877	16,000	1891				
1882	516	1908				
1892	2,500	1906				
1895	327	1937				

23-in. Wrought-Iron Bituminous-Lined and Coated Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1891	6,215	6,143	72
1940	0	0	0
Total	6,215	6,143	72

Retirements by Years

Year Installed	Feet	Year
1891	72	1934

30-in. Wrought-Iron Bituminous-Lined and Coated Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1863	2,770	0	2,770
1868	67,880	0	67,880
1870	65,700	27,944	37,756

30-in. Wrought-Iron Bituminous-Lined and Coated Mains (contd.)

Year Installed	Feet Installed	Feet In Service	Feet Retired
1885	4,513	4,513	0
1891	1,752	1,752	0
1896	9,050	9,050	0
1898	7,516	0	7,516
1907	30,550	28,043	2,507
1909	27,400	27,110	290
1911	13,512	12,196	1,316
1914	3,845	3,845	0
1922	8,052	6,552	1,500
1925	290	290	0
1926	2,729	1,529	1,200
1929	1,909	1,909	0
1940	0	0	0
Total	247,468	124,733	122,735

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1863	2,770	1926				
1868	2,500	1892	55,700	1906	9,680	1922
1870	3,740	1896	25,880	1898	692	1914
	2,155	1919	3,744	1922	1,305	1929
	240	1937				
1898	7,516	1911				
1907	407	1926	2,100	1934		
1909	290	1925				
1911	1,000	1935	316	1936		
1922	900	1926	600	1934		
1926	1,200	1934				

33-in. Wrought-Iron Bituminous-Lined and Coated Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1885	2,409	2,409	0
1940	0	0	0
Total	2,409	2,409	0

36-in. Wrought-Iron Bituminous-Lined and Coated Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1885	297	297	0
1888	136,633	73,366	63,267

36-in. Wrought-Iron Bituminous-Lined and Coated Mains (contd.)

Year Installed	Feet Installed	Feet In Service	Feet Retired
1900	5,420	420	5,000
1907	950	950	0
1913	3,194	3,194	0
1926	3,405	3,405	0
1940	0	0	0
Total	149,899	81,632	68,267

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1888	5,283	1924	140	1936	57,844	1938
1900	5,000	1938				

37-in. Wrought-Iron Bituminous-Lined and Coated Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1885	11,321	8,896	2,425
1895	1,414	1,414	0
1907	1,565	1,565	0
1940	0	0	0
Total	14,300	11,875	2,425

Retirements by Years

Year Installed	Feet	Year
1885	2,425	1912

44-in. Wrought-Iron Bituminous-Lined and Coated Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1885	102,439	91,531	10,908
1898	28,895	28,895	0
1901	967	753	214
1907	967	543	424
1916	533	533	0
1931	23	23	0
1940	0	0	0
Total	133,824	122,278	11,546

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1885	8,299	1888	900	1901	1,100	1930
	609	1940				
1901	214	1932				
1907	424	1916				

54-in. Wrought-Iron Bituminous-Lined and Coated Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1891	358	358	0
1904	16,757	16,757	0
1940	0	0	0
Total	17,115	17,115	0

10-in. Steel, Bituminous-Lined and Coated and Wrapped Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1938	9,580	9,580	0
1940	0	0	0
Total	9,580	9,580	0

16-in. Steel, Bituminous-Lined and Coated and Wrapped Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1923	15,660	14,457	1,203
1926	129	129	0
1928	4,277	4,277	0
1933	6	6	0
1940	0	0	0
Total	20,072	18,869	1,203

Retirements by Years

Year Installed	Feet	Year
1923	1,203	1933

20-in. Steel, Bituminous-Lined and Coated and Wrapped Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1926	7,104	7,104	0
1928	17,925	17,925	0
1929	1,776	1,776	0
1930	10,335	10,335	0
1931	3,800	3,800	0
1935	2,493	2,493	0
1936	22,154	22,154	0
1937	141	141	0
1940	0	0	0
Total	65,728	65,728	0

22-in. Steel, Bituminous-Lined and Coated and Wrapped Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1926	140	140	0
1940	0	0	0
Total	140	140	0

23½-in. Steel, Bituminous-Lined and Coated and Wrapped Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1923	9,136	8,707	429
1926	285	285	0
1927	95	95	0
1940	0	0	0
Total	9,516	9,087	429

Retirements by Years

Year Installed	*Feet*	*Year*	*Feet*	*Year*
1923	55	1928	374	1929

24-in. Steel, Bituminous-Lined and Coated and Wrapped Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1926	3,039	3,039	0
1928	9,275	9,275	0
1929	318	318	0
1933	5	5	0
1935	12	12	0
1936	13,794	13,794	0
1940	0	0	0
Total	26,443	26,443	0

28-in. Steel, Bituminous-Lined and Coated and Wrapped Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1936	7,480	7,480	0
1940	0	0	0
Total	7,480	7,480	0

30-in. Steel, Bituminous-Lined and Coated and Wrapped Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1915	3,250	3,250	0
1926	4,139	4,139	0
1929	11	11	0
1934	2,890	2,890	0
1935	6,897	6,897	0
1937	642	642	0
1938	63	63	0
1940	669	669	0
Total	18,561	18,561	0

36-in. Steel, Bituminous-Lined and Coated and Wrapped Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1924	5,200	5,200	0
1926	800	800	0
1930	300	300	0
1931	1,404	1,404	0
1934	4,209	4,209	0
1935	15,408	15,408	0
1936	13,594	13,594	0
1937	710	710	0
1938	28,026	28,026	0
1940	0	0	0
Total	69,651	69,651	0

44-in. Steel, Bituminous-Lined and Coated and Wrapped Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1930	883	883	0
1934	34,074	34,074	0
1936	5,568	5,568	0
1940	467	467	0
Total	40,992	40,992	0

48-in. Steel, Bituminous-Lined and Coated and Wrapped Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1931	11,290	11,290	0
1932	1,064	1,064	0
1940	0	0	0
Total	12,354	12,354	0

54-in. Steel, Bituminous-Lined and Coated and Wrapped Mains

Year Installed	Feet Installed	In Service	Retired
1928	57,629	57,629	0
1932	479	479	0
1935	8,849	8,849	0
1938	958	958	0
1940	0	0	0
Total	67,915	67,915	0

60-in. Steel, Bituminous-Lined and Coated and Wrapped Mains

Year Installed	Feet Installed	In Service	Retired
1933	250	250	0
1937	79,530	79,530	0
1938	9,981	9,981	0
1940	0	0	0
Total	89,761	89,761	0

66-in. Steel, Bituminous-Lined and Coated and Wrapped Mains

Year Installed	Feet Installed	In Service	Retired
1935	78,896	78,896	0
1940	0	0	0
Total	78,896	78,896	0

76-in. Steel, Bituminous-Lined and Coated and Wrapped Mains

Year Installed	Feet Installed	In Service	Retired
1935	3,858	3,858	0
1940	0	0	0
Total	3,858	3,858	0

16-in. Steel, Bituminous-Lined and Coated Mains

Year Installed	Feet Installed	In Service	Retired
1936	6,718	6,718	0
1940	0	0	0
Total	6,718	6,718	0

44-in. Steel, Bituminous-Lined and Coated Mains

Year Installed	Feet Installed	In Service	Retired
1924	15,600	15,600	0
1940	0	0	0
Total	15,600	15,600	0

60-in. Steel, Bituminous-Lined and Coated Mains

Year Installed	Feet Installed	In Service	Retired
1925	101,784	101,784	0
1940	0	0	0
Total	101,784	101,784	0

78-in. Steel, Bituminous-Lined and Coated Mains

Year Installed	Feet Installed	In Service	Retired
1939	649	649	0
1940	0	0	0
Total	649	649	0

16-in. Galvanized Steel, Bituminous-Lined and Coated (Submarine) Mains

Year Installed	Feet Installed	In Service	Retired
1888	13,563	790	12,773
1940	0	0	0
Total	13,563	790	12,773

Retirements by Years

Year Installed	Feet	Year
1888	12,773	1935

22-in. Galvanized Steel, Bituminous-Lined and Coated (Submarine) Mains

Year Installed	Feet Installed	In Service	Retired
1902	13,600	13,600	0
1940	0	0	0
Total	13,600	13,600	0

54-IN. STEEL, BITUMINOUS-LINED AND COATED, CONCRETE-WRAPPED (SUBMARINE) MAINS

Year Installed	Feet Installed	Feet In Service	Feet Retired
1936	5,958	5,958	0
1940	0	0	0
TOTAL	5,958	5,958	0

57-IN. CONCRETE, STEEL CYLINDER REINFORCED MAINS

Year Installed	Feet Installed	Feet In Service	Feet Retired
1933	6,822	6,822	0
1940	0	0	0
TOTAL	6,822	6,822	0

62-IN. CONCRETE, STEEL CYLINDER REINFORCED MAINS

Year Installed	Feet Installed	Feet In Service	Feet Retired
1935	26,014	26,014[1]	0
1940	0	0	0
TOTAL	26,014	26,014	0

69-IN. CONCRETE, STEEL CYLINDER REINFORCED MAINS

Year Installed	Feet Installed	Feet In Service	Feet Retired
1934	3,087	3,087	0
1940	0	0	0
TOTAL	3,087	3,087	0

Springfield, Massachusetts—Survival and Retirement Experience With Water Works Facilities

As of December 31, 1942

THE water supply of the city of Springfield, Mass., is provided by municipally owned works under the control of the Board of Water Commissioners. In addition to the city of Springfield, the municipal water works supplies West Wilbraham, Agawam, East Longmeadow, Longmeadow, Southwick, Mundale, Ludlow, Wilbraham and, in emergencies, West Springfield.

Springfield, located on the east bank of the Connecticut River, just east of the Berkshires in the western part of the state, is a distributing center with important diversified industries. Among the varied products made here are firearms, brass goods, foundry and machine shop products, confectionery, paper goods, automobile and radio parts and accessories, machinery, cotton and knit goods, leather goods, tools, mattresses and bed springs.

At the time of the study the estimated population of the city proper and its environs served by the system was about 190,000. Active service connections numbered 25,212, over 99 per cent of which were metered. The total amount of water furnished to the system during 1942 was 7.9 bil.gal. or a daily rate of 21.7 mil.gal. Approximately 87 per cent of the water was accounted for on customers' meters.

Development of the Existing System

The first developed supply in Springfield was a small private supply secured from springs in 1843. It was diverted to a reservoir and thence served through about 3 mi. of 4- to 7-in. log pipes. In 1848 a charter was granted to the Springfield Aqueduct Company, which immediately started the construction of several reservoirs and some 11 mi. of distribution pipe. In 1860, the City Aqueduct commenced operation under contract with the city but ceased operation in 1861 upon objection to its well supplies. In 1864 the original wood pipes of the Springfield Aqueduct Company were replaced with the cement pipe, invented by Jonathan Ball and made by Goodhue & Birnie of Springfield, which were prevalently being installed in many New England cities at that time. At the same time the original reservoir, Lombard Reservoir, was enlarged and the East and West Van Horn reservoirs constructed.

In 1872 the city consummated the purchase of the Springfield Aqueduct Company and commenced the operation of the works in 1873. In the three following years the Ludlow supply works were constructed. The present main supply works at Westfield Little River were started in 1907, the purification works were expanded in 1924 and the Cobble Mountain development was constructed in 1927–30.

The present supply is secured from surface supplies at two points, the main system at Westfield Little River, located in the Berkshires about 15 mi. west of the city, and the Ludlow sup-

TABLE 1

Summary of Mains
Springfield, Massachusetts

Size, in.	Kind	No. of Feet Installed	Percentage of Total	No. of Feet Retired	Percentage of Total	No. of Feet in Service	Percentage of Total	Year of First Installation	Average Age, yr.
4	Cast-iron unlined	81,909	3.5	39,710	8.3	42,199	2.3	1870	36.8
6		527,998	22.8	45,728	9.6	482,270	26.2	1866	41.9
8		699,662	30.1	20,209	4.3	679,453	36.8	1866	22.3
10		88,893	3.8	2,629	0.6	86,264	4.7	1873	23.6
12		104,052	4.5	5,686	1.2	98,366	5.3	1865	34.2
16		84,232	3.6	3,587	0.8	80,645	4.4	1865	30.7
20		7,913	0.4	10	0.0	7,903	0.4	1890	35.5
24		44,945	1.9	602	0.1	44,343	2.4	1874	28.3
30		51,832	2.2	1,669	0.4	50,163	2.7	1874	45.2
36		31,048	1.3	199	0.0	30,849	1.7	1894	40.2
42		2,254	0.1	75	0.0	2,179	0.1	1909	33.5
$\frac{3}{4}$	Wrought-iron and steel	1,069	0.0	1,069	0.2	0	0	1871	—
1		24,469	1.1	14,797	3.1	9,672	0.5	1873	17.0
$1\frac{1}{4}$		56,897	2.5	30,792	6.5	26,105	1.4	1870	14.7
$1\frac{1}{2}$		32,007	1.4	16,797	3.5	15,210	0.8	1883	15.5
2		107,078	4.6	59,396	12.5	47,682	2.6	1875	17.3
$2\frac{1}{2}$		159	0.0	0	0	159	0.0	1939	3.5
3		2,016	0.1	2,016	0.4	0	0	1877	—
10	Steel	28	0.0	0	0	28	0.0	1931	11.5
16		253	0.0	0	0	253	0.0	1929	12.1
18		13,144	0.6	0	0	13,144	0.7	1940	2.5
20		443	0.0	0	0	443	0.0	1926	5.3
24		71	0.0	0	0	71	0.0	1915	26.1
30		2,163	0.1	0	0	2,163	0.1	1909	33.5
36		3,822	0.2	0	0	3,822	0.2	1910	15.1
42		61,930	2.7	17	0	61,913	3.4	1909	33.3
48		18,309	0.8	0	0	18,309	1.0	1929	13.5
51		13	0	0	0	13	0	1929	13.5
54		16,155	0.7	0	0	16,155	0.9	1929	13.5
60		71	0.0	0	0	71	0.0	1932	10.5
66		279	0.0	0	0	279	0.0	1929	13.5
72		23	0.0	0	0	23	0.0	1929	13.5
$\frac{3}{4}$	Copper	60	0.0	0	0	60	0.0	1940	2.5
1		254	0.0	0	0	254	0.0	1940	2.2
$1\frac{1}{4}$		291	0.0	0	0	291	0.0	1941	1.5
$1\frac{1}{2}$	Brass	2	0.0	0	0	2	0.0	1941	1.5
2	Brass and Copper	578	0.0	0	0	578	0.0	1940	2.5

TABLE 1 (contd.)

Size, *in.*	Kind	No. of Feet Installed	Percentage of Total	No. of Feet Retired	Percentage of Total	No. of Feet in Service	Percentage of Total	Year of First Installation	Average Age, *yr.*
2	Cement	1,610	0.1	1,610	0.3	0	0	1865	—
3	Cement	51,765	2.2	51,765	10.9	0	0	1865	—
4	Cement	19,464	0.8	19,464	4.1	0	0	1865	—
6	Cement	53,737	2.3	53,737	11.3	0	0	1865	—
8	Cement	31,459	1.4	31,459	6.5	0	0	1864	—
10	Cement	2,485	0.1	2,485	0.5	0	0	1866	—
12	Cement	17,081	0.7	17,081	3.6	0	0	1864	—
16	Cement	16,206	0.7	16,206	3.4	0	0	1874	—
20	Cement	4,365	0.2	4,365	0.9	0	0	1874	—
24	Cement	52,789	2.3	33,329	7.0	19,460	1.1	1874	68.5
8	Asbestos-cement	3,127	0.1	0	0	3,127	0.2	1942	0.5
10	Asbestos-cement	1,232	0.1	0	0	1,232	0.1	1936	6.5
TOTAL		2,321,642	100.0	476,489	100.0	1,845,153	100.0		29.6
Percentage of Total		100.00		20.5		79.5			
Average Size, *in.*		10.5		6.8		11.5			

Mortality Survival Ratios

Size, *in.*	Kind	No. of Feet	Period Covered, *yr.*	Percentage
4	Cast-iron unlined	81,909	72.5	13.015
6	Cast-iron unlined	527,998	68.5	89.786
8	Cast-iron unlined	699,662	67.5	92.090
10 and 12	Cast-iron unlined	192,945	69.5	86.827
Over 12	Cast-iron unlined	222,224	68.5	96.422
¾–1½	Steel and wrought-iron	114,442	51.5	8.059
2–3	Steel and wrought-iron	109,253	59.5	0
2–4	Cement	72,839	43.5	0
6–10	Cement	87,681	45.5	0
12–20	Cement	37,652	40.5	0
24	Cement	52,789	68.5	36.863
10–72	Steel	116,704	33.5	99.973
¾–2	Copper and brass	1,185	2.5	100.000
8 and 10	Asbestos-cement	4,359	6.5	100.000
TOTAL		2,321,642		

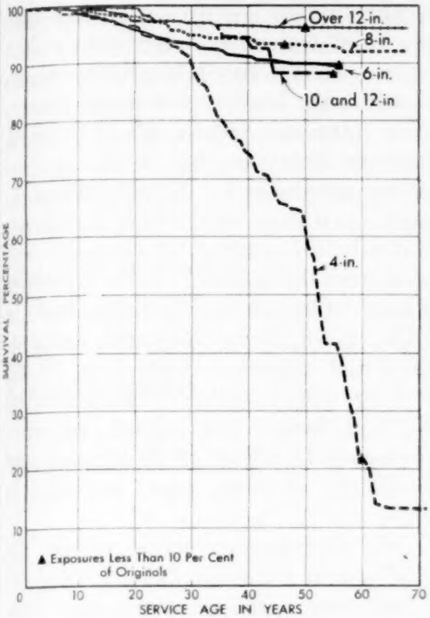

Fig. 1. Mortality Survival Curve—4–42-in. Cast-Iron Unlined Mains—Springfield, Massachusetts

Base: Feet	Survival: 1865–1942	
Size	Exposures	Retirements
in.	*ft.*	*ft.*
4	81,909	39,710
6	527,998	45,728
8	699,662	20,209
10 and 12	192,945	8,315
Over 12	222,224	6,142

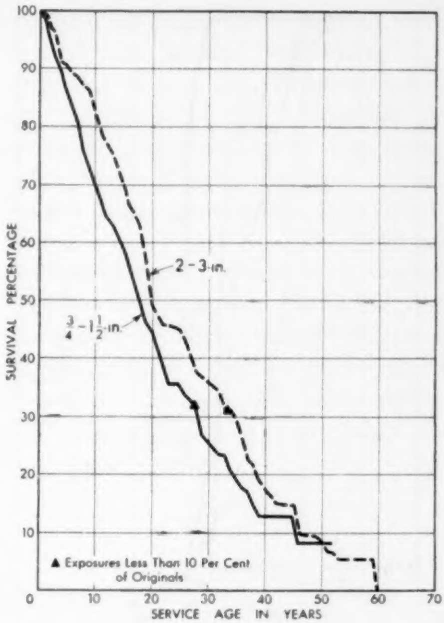

Fig. 2. Mortality Survival Curve—$\frac{3}{4}$–3-in. Wrought-Iron and Steel Mains—Springfield, Massachusetts

Base: Feet	Survival: 1870–1942	
Size	Exposures	Retirements
in.	*ft.*	*ft.*
$\frac{3}{4}$–$1\frac{1}{2}$	114,442	63,455
2–3	109,253	61,412

ply, located in the towns of Ludlow and Belchertown northeast of the city. The latter works supply the town of Ludlow and a part of Wilbraham and are normally valved off from the main system at the Chicopee River.

The Westfield Little River system has a drainage area of 48.5 sq.mi., providing, with its storage, a safe yield of 55 mgd. Borden Brook reservoir, built in 1908–09, has an impounding capacity of 2.5 bil.gal. The supply from this reservoir flows through the natural stream bed to Cobble Mountain Reservoir. This reservoir, built in 1928–30 across Little River, is formed by a hydraulic-fill dam impounding 22.8 bil.gal. A 10-ft. tunnel extends 8,000 ft. to penstocks, which descend to a power house on the bank of Little River and to a small reservoir which diverts the water, after purification, to the city about 13 mi. away. The purification works include sedimentation basin, aerator and covered slow sand filters having an aggregate capacity of from 24 to 30 mgd.

The filtered supply is conveyed to distribution reservoirs at Provin Mountain through a 42-in. steel pipeline about 40,000 ft. long. The Provin

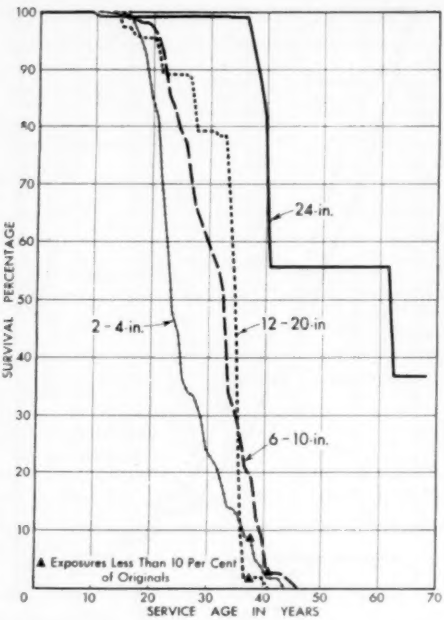

FIG. 3. Mortality Survival Curve—2-24-in. Cement Mains—Springfield, Massachusetts

BASE: Feet	SURVIVAL: 1864–1942	
SIZE	EXPOSURES	RETIREMENTS
in.	*ft.*	*ft.*
2–4	72,839	72,839
6–10	87,681	87,681
12–20	37,652	37,652
24	52,789	33,329

Mountain reservoirs are concrete covered basins; one built in 1909 holds 17 mil.gal. and the second built in 1932 holds 12.3 mil.gal. Two pipelines, over diverging routes, convey the supply to the city. The first line, built in 1909, extends 22,170 ft. as 42-in. steel to the Connecticut River, continuing as two 30-in. steel pipes across the river and thence as 42-in. cast-iron pipe to the distribution system. The second line is welded steel, laid in 1929, and extends 16,100 ft. as 54-in. and 16,665 ft. as 48-in., crossing the Connecticut River as two lines of 36-in. pipe 1,700 ft. long laid in the river bed.

The Ludlow supply is a surface supply from watersheds aggregating 20.5 sq.mi. It is secured largely by diversion into the Ludlow distributing reservoir. The safe yield is about 11 mgd. Ludlow Reservoir has a storage capacity of about 1.4 bil.gal. Four 3-mgd. open slow sand filters purify the water before service. Two mains extend from the reservoir to the Chicopee River. One line, originally laid in 1874, is of 24-in. diameter, cement-lined and -coated wrought-iron, 19,460 ft. long, with a section of cast-iron pipe 4,805 ft. long. The second line, consisting of 13,388 ft. of 36-in. pipe and 14,217 ft. of 30-in. pipe, was laid in 1894.

The distribution mains within the city system comprise 355 mi. of $\frac{3}{4}$- to 72-in. pipe, predominately cast iron. There are 25,212 active services, 25,081 of which are metered. They are of varying standard kinds and sizes of pipe and are paid for by the consumers. The system has 9,673 valves, 3,061 public fire hydrants and 25,845 meters.

Basis of Study

The records of installation and retirement of pipe are accurately reflected in annual reports from 1864 to the present date. The basis of this study is a similar study of the mortality of the pipe system in Springfield carried forward by the Supervising Co-ordinator of the Committee on Survival and Retirement, in collaboration with Reeves Newsom, and reported in papers before the Association and published in the October 1939 and May 1940 JOURNALS. This study has been brought up to the date of this report.

Mortality Survival Study

Mortality studies of distribution and transmission mains without classifica-

tion only were made. Table 1 is a summary of the pipe installed, the amount retired and that still in service, as well as other pertinent data. Figures 1, 2 and 3 show the mortality survival curves covering the records of the amount and sizes of pipe grouped as shown.

Causes of Retirement

The causes of retirement of mains were not determined.

Acknowledgment

The collection and compilation of data relative to the installation and retirement of mains in Springfield were carried out by the Supervising Coordinator in the first instance before the formation of the Committee on Survival and Retirement Experience With Water Works Facilities and reported to the Association as previously stated. These studies were continued to bring them to the date of this report. The city of Springfield Municipal Water Works, through Leland G. Carlton, Superintendent, member of the above Committee, co-operated in furnishing the original records from which the data were secured.

Summary of Installations and Retirements
Springfield, Massachusetts

MAINS

4-in. Cast-Iron Unlined Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1870	173	173	0
1873	433	0	433
1874	292	0	292
1875	65	0	65
1876	5,703	886	4,817
1877	4,464	1,263	3,201
1878	5,464	3	5,461
1879	6,276	1,384	4,892
1880	1,895	222	1,673
1881	1,980	0	1,980
1882	1,595	0	1,595
1883	2,286	399	1,887
1884	1,589	0	1,589
1885	998	353	645
1886	471	117	354
1887	1,225	971	254
1888	1,046	404	642
1889	762	130	632
1890	2,610	1,955	655
1891	1,595	1,203	392
1892	508	204	304
1893	2,290	607	1,683
1894	696	190	506
1895	1,331	248	1,083
1896	1,309	212	1,097
1897	1,297	1,246	51
1898	264	253	11
1899	1,393	1,095	298
1900	3,259	3,259	0
1901	629	12	617
1903	2,204	590	1,614

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1904	20	0	20
1905	108	36	72
1906	8	8	0
1907	180	38	142
1909	1,625	1,237	388
1910	3,175	3,161	14
1911	2,389	2,389	0
1912	1,638	1,638	0
1913	3,833	3,681	152
1914	3,769	3,769	0
1915	2,500	2,500	0
1916	781	781	0
1917	576	576	0
1919	135	135	0
1920	299	296	3
1921	128	128	0
1922	12	12	0
1923	457	282	175
1924	492	492	0
1925	150	150	0
1928	551	551	0
1929	497	497	0
1932	512	500	12
1933	278	278	0
1935	10	10	0
1936	240	231	9
1939	386	386	0
1941	14	14	0
1942	1,044	1,044	0
Total	81,909	42,199	39,710

Retirements by Years

Year Installed	*Feet*	*Year*	*Feet*	*Year*	*Feet*	*Year*
1873	51	1885	80	1889	242	1910
	60	1911				
1874	52	1908	240	1909		
1875	12	1895	53	1910		
1876	1,360	1906	42	1908	24	1910
	131	1911	72	1913	52	1914
	483	1917	510	1921	2,086	1935
	57	1940				
1877	36	1885	362	1903	34	1910
	80	1911	9	1912	25	1913
	59	1914	676	1927	1,065	1935
	792	1939	63	1940		
1878	211	1906	416	1909	30	1910

Year Installed	*Feet*	*Year*	*Feet*	*Year*	*Feet*	*Year*
1878	64	1911	18	1912	69	1913
	9	1914	1,113	1917	107	1930
	338	1931	654	1934	1,450	1935
	982	1940				
1879	17	1888	24	1895	24	1902
	399	1905	338	1908	599	1923
	2,562	1931	394	1935	535	1940
1880	513	1908	54	1910	584	1911
	210	1921	312	1939		
1881	15	1908	450	1917	562	1931
	945	1934	8	1939		
1882	508	1888	524	1935	563	1939
1883	712	1933	338	1934	837	1935

4-in. Cast-Iron Unlined Mains (contd.)

Retirements by Years (contd.)

Year Installed	Feet	Year	Feet	Year	Feet	Year
1884	455	1896	52	1907	186	1913
	366	1931	511	1934	19	1935
1885	16	1904	579	1906	50	1934
1886	126	1907	228	1939		
1887	124	1907	13	1908	117	1910
1888	83	1908	163	1910	29	1912
	77	1931	290	1940		
1889	20	1898	95	1909	272	1910
	14	1911	6	1918	225	1939
1890	4	1898	52	1908	9	1909
	2	1934	10	1935	3	1937
	114	1939	461	1941		
1891	228	1908	88	1923	76	1931
1892	304	1908				
1893	31	1895	12	1905	19	1906
	32	1920	514	1923	665	1934
	410	1935				
1894	506	1939				
1895	197	1910	169	1931	717	1939

Year Installed	Feet	Year	Feet	Year	Feet	Year
1896	13	1912	5	1914	1,079	1930
1897	4	1905	6	1908	4	1933
	37	1935				
1898	11	1920				
1899	9	1909	10	1918	279	1939
1901	15	1907	15	1913	587	1938
1903	23	1909	62	1928	1,529	1936
1904	20	1938				
1905	72	1923				
1907	142	1914				
1909	14	1910	148	1919	77	1935
	149	1939				
1910	14	1931				
1913	42	1927	17	1936	93	1937
1920	3	1928				
1923	143	1930	32	1935		
1932	12	1935				
1936	9	1936				

6-in. Cast-Iron Unlined Mains

Year	Feet		
Installed	Installed	In Service	Retired
1866	170	0	170
1870	155	0	155
1871	1,117	0	1,117
1875	1,938	1,231	707
1876	2,456	1,640	816
1877	2,136	2,092	44
1879	850	0	850
1880	600	0	600
1881	7,041	6,947	94
1882	90	90	0
1883	3,304	2,647	657
1884	9,299	8,083	1,216
1885	5,167	4,504	663
1886	12,501	10,972	1,529
1887	20,510	17,696	2,814
1888	17,940	16,697	1,243
1889	20,060	18,865	1,195
1890	17,038	14,091	2,947
1891	17,500	16,479	1,021
1892	21,620	19,948	1,672
1893	18,786	14,840	3,946
1894	15,483	15,418	65
1895	18,184	16,237	1,947
1896	14,966	14,228	738
1897	35,501	32,396	3,105
1898	27,706	23,062	4,644
1899	14,154	13,605	549
1900	7,159	6,587	572
1901	6,036	5,567	469
1902	7,304	7,271	33
1903	11,615	10,946	669
1904	9,365	8,267	1,098
1905	13,440	11,071	2,369
1906	12,568	11,532	1,036
1907	11,480	10,540	940
1908	12,714	12,522	192
1909	14,338	13,271	1,067
1910	14,305	13,343	962
1911	21,351	20,520	831
1912	17,889	17,569	320
1913	12,855	12,619	236
1914	4,469	4,454	15
1915	4,198	4,198	0
1916	3,771	3,696	75
1917	2,444	2,384	60
1918	2,144	2,144	0
1919	961	831	130
1920	960	960	0
1921	1,213	1,213	0
1922	1,174	1,174	0
1923	483	483	0
1924	1,938	1,801	137
1925	1,568	1,568	0
1926	537	537	0
1927	1,444	1,444	0
1928	1,482	1,482	0
1929	926	926	0
1930	1,823	1,823	0

6-in. Cast-Iron Unlined Mains (contd.)

Year Installed	Feet Installed	Feet In Service	Feet Retired	Year Installed	Feet Installed	Feet In Service	Feet Retired
1931	160	160	0	1938	2,922	2,922	0
1932	2,011	2,011	0	1939	2,620	2,616	4
1933	113	113	0	1940	1,045	1,045	0
1934	3,337	3,328	9	1941	884	884	0
1935	559	559	0	1942	771	771	0
1936	784	784	0				
1937	2,566	2,566	0	Total	527,998	482,270	45,728

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1866	170	1890				
1870	155	1903				
1871	1,117	1893				
1875	60	1905	549	1914	98	1915
1876	1	1908	815	1911		
1877	44	1910				
1879	850	1915				
1880	600	1911				
1881	26	1910	24	1911	30	1912
	14	1913				
1883	447	1909	135	1911	75	1915
1884	20	1890	171	1908	336	1909
	370	1910	14	1914	14	1915
	175	1921	116	1931		
1885	48	1889	16	1890	38	1907
	44	1908	284	1909	24	1910
	72	1911	10	1913	25	1915
	42	1918	60	1938		
1886	1,127	1909	57	1910	319	1913
	11	1928	15	1930		
1887	548	1907	678	1908	82	1909
	294	1910	870	1918	276	1921
	66	1922				
1888	7	1890	42	1891	1,083	1906
	46	1910	38	1913	27	1940
1889	7	1890	25	1908	42	1909
	49	1911	713	1913	106	1920
	237	1925	16	1931		
1890	11	1891	10	1903	389	1905
	37	1908	1,452	1909	71	1910
	743	1911	25	1915	42	1918
	167	1941				
1891	255	1908	45	1909	266	1910
	455	1913				
1892	54	1908	184	1909	429	1910
	176	1911	189	1917	12	1935
	551	1937	77	1939		
1893	10	1907	101	1909	157	1910
	1,566	1914	44	1915	3	1916
	1,555	1934	510	1937		
1894	12	1908	12	1910	17	1911
	24	1914				
1895	49	1900	50	1903	167	1904
1895	38	1905	75	1909	281	1911
	178	1912	70	1913	4	1914
	492	1926	188	1932	355	1939
1896	322	1909	68	1912	5	1914
	51	1915	292	1932		
1897	67	1908	1,401	1909	302	1911
	88	1912	530	1913	36	1915
	29	1931	234	1933	418	1935
1898	51	1905	1,217	1909	64	1910
	485	1912	1,731	1913	20	1915
	764	1927	240	1933	72	1937
1899	6	1903	12	1908	369	1910
	23	1911	23	1913	116	1933
1900	28	1912	15	1913	130	1914
	3	1916	228	1917	72	1921
	96	1922				
1901	101	1909	2	1932	302	1933
	64	1938				
1902	33	1912				
1903	322	1911	21	1913	130	1930
	110	1934	86	1935		
1904	253	1909	259	1911	306	1913
	280	1933				
1905	32	1907	24	1909	48	1911
	647	1914	1,253	1916	49	1918
	250	1929	20	1931	46	1933
1906	338	1911	24	1914	156	1933
	115	1938	103	1939	300	1942
1907	27	1913	10	1915	18	1917
	246	1928	391	1933	68	1941
	180	1942				
1908	192	1914				
1909	15	1913	3	1915	98	1920
	555	1928	396	1930		
1910	19	1911	87	1913	846	1914
	10	1915				
1911	189	1913	22	1914	10	1915
	23	1919	418	1921	155	1927
	3	1929	11	1936		
1912	33	1914	12	1917	275	1930
1913	124	1919	112	1922		
1914	15	1931				
1916	75	1927				

6-in. Cast-Iron Unlined Mains (contd.)

Retirements by Years (contd.)

Year Installed	Feet	Year	Feet	Year	Feet	Year	Year Installed	Feet	Year	Feet	Year	Feet	Year
1917	60	1927					1934	9	1934				
1919	130	1927					1939	4	1941				
1924	137	1941											

8-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired	Year Installed	Feet Installed	Feet In Service	Feet Retired
1866	115	0	115	1910	5,207	5,207	0
1871	36	0	36	1911	7,024	6,252	772
1873	1,505	0	1,505	1912	11,636	11,589	47
1875	8,144	7,489	655	1913	22,572	22,514	58
1876	8,029	6,782	1,247	1914	21,740	21,677	63
1877•	230	0	230	1915	29,473	29,443	30
1880	3,402	3,402	0	1916	17,428	17,381	47
1881	2,428	1,963	465	1917	12,357	12,357	0
1882	4,359	4,139	220	1918	2,121	2,121	0
1883	2,158	300	1,858	1919	14,144	14,144	0
1884	1,624	1,615	9	1920	16,532	16,529	3
1885	1,612	510	1,102	1921	18,871	18,834	37
1886	3,652	3,264	388	1922	16,615	16,615	0
1887	4,817	4,471	346	1923	21,954	21,954	0
1888	5,747	4,360	1,387	1924	33,818	33,650	168
1889	2,568	1,347	1,221	1925	35,911	35,647	264
1890	2,029	1,882	147	1926	29,192	29,183	9
1891	4,328	4,222	106	1927	12,105	12,057	48
1892	2,771	2,214	557	1928	12,287	12,287	0
1893	4,041	2,413	1,628	1929	32,734	32,734	0
1894	2,548	2,036	512	1930	14,755	14,755	0
1895	7,310	7,071	239	1931	14,185	14,173	12
1896	9,341	9,228	113	1932	13,044	13,044	0
1897	6,224	5,057	1,167	1933	9,944	9,911	33
1898	3,810	3,810	0	1934	7,849	7,849	0
1899	3,095	3,095	0	1935	9,598	9,598	0
1900	2,457	2,457	0	1936	3,211	3,211	0
1901	2,931	1,075	1,856	1937	10,016	10,016	0
1902	2,480	2,480	0	1938	13,041	13,041	0
1903	2,875	2,630	245	1939	25,881	25,881	0
1904	698	698	0	1940	26,925	26,925	0
1905	9,448	9,009	439	1941	24,594	24,594	0
1906	4,956	4,607	349	1942	8,401	8,401	0
1907	5,685	5,350	335				
1908	11,429	11,340	89	Total	699,662	679,453	20,209
1909	5,615	5,563	52				

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year	Year Installed	Feet	Year	Feet	Year	Feet	Year
1866	115	1915					1876	56	1902	410	1905	11	1910
1871	36	1896					1877	230	1909				
1873	280	1893	1,225	1899			1881	465	1910				
1875	28	1888	15	1909	128	1910	1882	125	1909	58	1914	37	1927
	21	1913	136	1918	327	1931	1883	1,858	1896				
1876	700	1893	50	1895	20	1901	1884	9	1909				

8-in. Cast-Iron Unlined Mains (contd.)

Retirements by Years (contd.)

Year Installed	Feet	Year	Feet	Year	Feet	Year
1885	716	1907	28	1910	325	1913
	33	1915				
1886	388	1908				
1887	16	1908	19	1910	311	1914
1888	19	1908	1,316	1909	52	1914
1889	1,221	1915				
1890	3	1908	9	1909	135	1913
1891	21	1901	20	1908	21	1910
	28	1918	16	1930		
1892	541	1908	16	1910		
1893	1,441	1896	24	1914	163	1927
1894	31	1900	6	1901	475	1915
1895	85	1900	87	1911	67	1939
1896	93	1908	20	1918		
1897	404	1908	23	1923	47	1936
	7	1937	686	1938		
1901	76	1907	1,780	1909		
1903	227	1908	18	1915		
1905	180	1913	67	1931	192	1933

Year Installed	Feet	Year	Feet	Year	Feet	Year
1906	328	1910	21	1914		
1907	10	1908	12	1910	313	1913
1908	15	1913	64	1938	10	1941
1909	12	1910	40	1914		
1911	40	1912	378	1913	354	1937
1912	26	1913	9	1915	12	1936
1913	14	1936	44	1939		
1914	12	1915	36	1928	15	1936
1915	30	1936				
1916	47	1926				
1920	3	1927				
1921	37	1937				
1924	168	1930				
1925	190	1926	74	1941		
1926	9	1937				
1927	48	1942				
1931	12	1933				
1933	33	1933				

10-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1873	1,004	1,004	0
1874	3,211	1,638	1,573
1875	416	416	0
1879	31	31	0
1880	559	538	21
1886	12	12	0
1900	1,135	1,135	0
1905	752	0	752
1906	1,430	1,430	0
1907	496	496	0
1908	14,012	14,006	6
1910	5,119	4,870	249
1911	653	653	0
1912	438	428	10
1913	4,642	4,642	0
1914	4,060	4,060	0
1915	3,352	3,334	18
1916	1,845	1,845	0
1917	1,165	1,165	0
1918	2,544	2,544	0
1919	264	264	0
1920	1,394	1,394	0

Year Installed	Feet Installed	Feet In Service	Feet Retired
1921	3,835	3,835	0
1922	3,937	3,937	0
1923	1,399	1,399	0
1924	3,647	3,647	0
1925	1,585	1,585	0
1926	1,307	1,307	0
1927	421	421	0
1928	2,325	2,325	0
1929	630	630	0
1930	1,264	1,264	0
1931	321	321	0
1932	3,021	3,021	0
1933	610	610	0
1934	5,590	5,590	0
1936	644	644	0
1938	65	65	0
1939	704	704	0
1941	549	549	0
1942	8,505	8,505	0
Total	88,893	86,264	2,629

Retirements by Years

Year Installed	Feet	Year	Feet	Year
1874	28	1891	1,545	1918
1880	21	1918		
1905	752	1913		
1908	6	1914		

Year Installed	Feet	Year	Feet	Year
1910	249	1929		
1912	10	1914		
1915	8	1918	10	1936

12-in. Cast-Iron Unlined Mains

Year	Feet			Year	Feet		
Installed	*Installed*	*In Service*	*Retired*	*Installed*	*Installed*	*In Service*	*Retired*
1865	200	0	200	1914	4,825	4,825	0
1873	240	84	156	1915	595	595	0
1875	3,766	2,710	1,056	1917	2,734	2,734	0
1883	2,688	2,688	0	1919	1,412	1,412	0
1884	735	735	0	1920	106	106	0
1885	4,589	4,589	0	1921	2,049	2,049	0
1886	3,608	3,608	0	1922	1,879	1,879	0
1888	2,868	2,654	214	1923	1,224	1,224	0
1889	1,853	1,169	684	1924	3,427	3,427	0
1890	4,235	2,800	1,435	1925	2,266	2,266	0
1892	1,192	1,192	0	1926	698	698	0
1893	1,312	1,051	261	1927	1,829	1,829	0
1894	900	900	0	1928	958	958	0
1895	6,164	6,164	0	1930	2,321	2,321	0
1896	55	49	6	1931	250	250	0
1897	28	0	28	1932	1,844	1,844	0
1900	884	884	0	1933	1,895	1,895	0
1902	950	950	0	1934	1,658	1,658	0
1906	1,287	1,287	0	1937	280	280	0
1907	2,018	1,855	163	1938	513	513	0
1908	5,106	5,106	0	1939	621	621	0
1909	236	229	7	1940	103	103	0
1910	2,043	2,043	0	1941	229	229	0
1911	2,175	2,175	0	1942	0	0	0
1912	678	678	0				
1913	20,526	19,050	1,476	Total	104,052	98,366	5,686

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year	Year Installed	Feet	Year	Feet	Year	Feet	Year
1865	200	1909					1893	261	1927				
1873	156	1907					1896	6	1909				
1875	25	1908	930	1910	101	1940	1897	28	1909				
1888	214	1913					1907	163	1921				
1889	15	1908	9	1910	660	1929	1909	7	1914				
1890	15	1908	1,420	1909			1913	722	1928	239	1929	515	1930

16-in. Cast-Iron Unlined Mains

Year	Feet			Year	Feet		
Installed	*Installed*	*In Service*	*Retired*	*Installed*	*Installed*	*In Service*	*Retired*
1865	200	0	200	1906	2,224	2,224	0
1874	1,956	1,956	0	1908	2,447	2,447	0
1875	3,918	3,600	318	1909	1,636	1,636	0
1882	1,205	1,205	0	1910	1,765	1,765	0
1884	1,589	1,589	0	1911	3,369	3,369	0
1885	1,515	1,515	0	1912	2,547	2,547	0
1889	3,371	3,371	0	1913	66	66	0
1890	318	318	0	1914	16,436	16,392	44
1896	3,202	3,202	0	1915	763	763	0
1897	5	0	5	1917	829	829	0
1899	2,755	0	2,755	1918	1,244	1,244	0
1900	265	0	265	1920	8,337	8,337	0

16-in. Cast-Iron Unlined Mains (contd.)

Year Installed	Feet Installed	Feet In Service	Feet Retired
1921	5,151	5,151	0
1922	3,708	3,708	0
1924	234	234	0
1926	3,177	3,177	0
1929	23	23	0
1931	102	102	0
1932	207	207	0
1933	3,181	3,181	0
1935	1,519	1,519	0
1937	3,016	3,016	0
1938	686	686	0
1940	8	8	0
1941	1,008	1,008	0
1942	250	250	0
Total	84,232	80,645	3,587

Retirements by Years

Year Installed	Feet	Year	Feet	Year
1865	200	1909		
1875	318	1909		
1897	5	1909		
1899	8	1913	2,747	192[illegible]
1900	265	1909		
1914	44	1937		

20-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1890	10	0	10
1894	1,672	1,672	0
1908	1,778	1,778	0
1911	2,324	2,324	0
1912	2,129	2,129	0
1942	0	0	0
Total	7,913	7,903	10

Retirements by Years

Year Installed	Feet	Year
1890	10	1909

24-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1874	3,736	3,390	346
1885	215	80	135
1893	350	350	0
1894	1,980	1,980	0
1907	40	40	0
1910	11,442	11,442	0
1911	490	490	0
1912	2,540	2,419	121
1913	3,752	3,752	0
1914	8,245	8,245	0
1915	835	835	0
1936	11,149	11,149	0
1937	171	171	0
1942	0	0	0
Total	44,945	44,343	602

Retirements by Years

Year Installed	Feet	Year	Feet	Year
1874	346	1894		
1885	135	1914		
1912	9	1936	112	193[illegible]

30-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1874	120	120	0
1893	9,846	9,785	61
1894	30,053	28,475	1,578
1899	300	270	30
1907	7,284	7,284	0
1909	100	100	0
1910	2,345	2,345	0
1917	1,784	1,784	0
1942	0	0	0
Total	51,832	50,163	1,669

Retirements by Years

Year Installed	Feet	Year
1893	61	1915
1894	1,578	1917
1899	30	1940

36-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1894	13,388	13,388	0
1907	2,563	2,563	0
1908	4,167	4,167	0
1909	8,017	7,818	199
1910	2,864	2,864	0
1932	10	10	0
1938	39	39	0
1942	0	0	0
Total	31,048	30,849	199

Retirements by Years

Year Installed	Feet	Year	Feet	Year
1909	39	1909	160	1914

42-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1909	2,254	2,179	75
1942	0	0	0
Total	2,254	2,179	75

Retirements by Years

Year Installed	Feet	Year
1909	75	1931

$\frac{3}{4}$-in. Wrought-Iron and Steel Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1871	180	0	180
1917	160	0	160
1921	19	0	19
1922	435	0	435
1924	195	0	195
1926	80	0	80
1940	0	0	0
Total	1,069	0	1,069

Retirements by Years

Year Installed	Feet	Year
1871	180	1898
1917	160	1940
1921	19	1923
1922	435	1928
1924	195	1936
1926	80	1929

1-in. Wrought-Iron and Steel Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired	Year Installed	Feet Installed	Feet In Service	Feet Retired
1873	260	0	260	1915	662	235	427
1876	300	0	300	1916	505	0	505
1881	447	0	447	1917	326	75	251
1882	571	0	571	1918	488	161	327
1885	255	0	255	1919	107	0	107
1887	88	0	88	1920	997	470	527
1888	234	0	234	1921	710	162	548
1889	48	0	48	1922	2,341	944	1,397
1892	211	0	211	1923	1,882	1,237	645
1896	100	0	100	1924	2,903	902	2,001
1897	136	75	61	1925	2,065	1,262	803
1898	335	250	85	1926	908	711	197
1900	88	20	68	1928	589	391	198
1902	147	56	91	1929	193	193	0
1904	9	0	9	1932	122	42	80
1905	22	0	22	1933	253	253	0
1906	557	0	557	1934	357	326	31
1907	33	0	33	1936	371	347	24
1908	399	0	399	1937	144	144	0
1910	121	0	121	1938	129	0	129
1911	38	0	38	1940	322	322	0
1912	954	98	856	1942	804	804	0
1913	1,277	0	1,277				
1914	661	192	469	Total	24,469	9,672	14,797

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year	Year Installed	Feet	Year	Feet	Year	Feet	Year
1873	260	1902					1914	134	1921	104	1925	101	1927
1876	100	1888	200	1895			1915	4	1915	31	1916	69	1917
1881	447	1892						24	1922	240	1926	28	1928
1882	250	1894	220	1903	101	1917		30	1929	1	1932		
1885	255	1886					1916	13	1917	10	1920	482	1921
1887	88	1908					1917	18	1922	208	1925	25	1937
1888	234	1897					1918	63	1919	264	1925		
1889	24	1908	17	1915	7	1916	1919	30	1920	20	1922	36	1930
1892	211	1899						21	1932				
1896	51	1899	10	1904	39	1905	1920	362	1927	165	1932		
1897	42	1905	4	1912	15	1913	1921	365	1922	44	1923	139	1928
1898	24	1917	61	1932			1922	51	1923	155	1924	238	1926
1900	68	1906						54	1928	484	1929	43	1933
1902	70	1909	21	1936				67	1936	58	1939	247	1940
1904	9	1908					1923	319	1925	147	1926	38	1928
1905	22	1911						141	1940				
1906	557	1921					1924	511	1925	753	1926	28	1931
1907	33	1913						68	1932	249	1939	392	1940
1908	40	1909	100	1910	259	1915	1925	40	1925	118	1926	99	1927
1910	121	1914						62	1928	48	1929	398	1932
1911	38	1925						38	1937				
1912	218	1913	146	1915	24	1917	1926	197	1929				
	380	1921	88	1931			1928	198	1932				
1913	102	1913	191	1914	136	1916	1932	80	1941				
	138	1919	18	1920	40	1921	1934	31	1936				
	76	1922	210	1923	308	1924	1936	24	1940				
	58	1931					1938	129	1941				
1914	40	1914	30	1915	60	1919							

1¼-in. Wrought-Iron and Steel Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1870	31	0	31
1876	643	0	643
1881	131	0	131
1882	722	0	722
1883	149	0	149
1884	307	0	307
1885	169	0	169
1887	895	0	895
1888	928	0	928
1889	721	0	721
1890	471	0	471
1891	573	0	573
1892	153	0	153
1893	2,182	0	2,182
1894	1,082	364	718
1895	161	0	161
1896	577	0	577
1897	593	106	487
1898	645	202	443
1899	525	0	525
1900	1,205	0	1,205
1901	299	191	108
1902	133	53	80
1903	15	0	15
1904	667	0	667
1906	273	174	99
1907	109	0	109
1908	971	0	971
1909	1,186	87	1,099
1911	325	140	185
1912	807	385	422
1913	418	179	239
1914	1,209	691	518
1915	380	152	228
1916	1,031	619	412
1917	493	164	329
1918	613	224	389
1919	430	149	281
1921	1,647	939	708
1922	4,283	2,173	2,110
1923	2,346	297	2,049
1924	4,468	1,762	2,706
1925	3,523	2,049	1,474
1926	1,868	1,160	708
1927	1,691	1,482	209
1928	799	604	195
1929	556	556	0
1930	2,060	1,345	715
1931	67	67	0
1932	1,267	710	557
1933	602	185	417
1934	632	490	142
1935	255	255	0
1936	1,697	1,630	67
1937	1,430	1,430	0
1938	277	150	127
1939	953	953	0
1940	966	700	266
1941	2,472	2,472	0
1942	816	816	0
Total	56,897	26,105	30,792

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1870	31	1896				
1876	211	1888	432	1897		
1881	131	1904				
1882	225	1892	200	1893	181	1894
	116	1895				
1883	149	1928				
1884	307	1886				
1885	169	1886				
1887	559	1895	74	1914	262	1920
1888	387	1889	348	1894	193	1905
1889	326	1894	395	1906		
1890	327	1894	144	1911		
1891	106	1892	31	1894	158	1907
	150	1908	128	1913		
1892	153	1908				
1893	150	1894	62	1895	94	1898
	1,084	1907	39	1908	656	1910
	97	1912				
1894	209	1899	181	1908	146	1912
1894	182	1932				
1895	66	1900	95	1912		
1896	190	1904	77	1914	310	1929
1897	142	1910	142	1917	203	1934
1898	284	1905	124	1913	35	1929
1899	100	1908	275	1914	150	1934
1900	132	1906	192	1911	356	1922
	133	1926	108	1929	284	1937
1901	75	1905	33	1909		
1902	80	1927				
1903	15	1908				
1904	552	1929	115	1934		
1906	8	1908	91	1922		
1907	109	1908				
1908	267	1915	30	1917	674	1924
1909	7	1910	157	1911	13	1914
	327	1923	469	1926	110	1929
	16	1937				
1911	40	1913	46	1914	99	1929

1¼-in. Wrought-Iron and Steel Mains (contd.)

Retirements by Years (contd.)

Year Installed	Feet	Year	Feet	Year	Feet	Year
1912	53	1916	61	1923	107	1929
	201	1930				
1913	59	1914	180	1924		
1914	300	1924	10	1925	208	1940
1915	73	1923	155	1932		
1916	12	1920	267	1925	133	1932
1917	126	1924	87	1930	116	1933
1918	148	1927	241	1931		
1919	36	1920	245	1939		
1921	297	1922	223	1924	98	1932
	90	1940				
1922	364	1924	77	1925	95	1926
	147	1928	328	1930	544	1932
	122	1937	433	1940		
1923	350	1925	448	1926	321	1927
	596	1928	259	1929	75	1933
1924	117	1924	603	1925	23	1926
1924	186	1927	185	1928		
	440	1930	44	1933	161	1934
	654	1939	46	1940	247	1942
1925	218	1926	115	1929	144	1932
	291	1939	503	1940	73	1941
	130	1942				
1926	85	1929	201	1938	24	1939
	148	1941	250	1942		
1927	16	1931	193	1933		
1928	97	1932	21	1933	77	1934
1930	263	1937	452	1941		
1932	142	1937	307	1940	108	1941
1933	267	1939	150	1941		
1934	142	1939				
1936	67	1942				
1938	127	1941				
1940	266	1942				

1½-in. Wrought-Iron and Steel Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1883	203	0	203
1884	325	0	325
1886	49	0	49
1889	523	0	523
1891	54	54	0
1892	63	0	63
1894	142	0	142
1895	146	0	146
1896	480	0	480
1898	1,610	0	1,610
1899	820	536	284
1900	725	0	725
1901	467	0	467
1902	352	0	352
1903	531	0	531
1904	508	199	309
1906	718	437	281
1907	163	0	163
1909	273	138	135
1910	57	0	57
1911	1,437	392	1,045
1913	444	0	444
1917	244	0	244
1919	342	280	62
1920	1,102	210	892
1921	546	105	441
1922	3,009	808	2,201
1923	2,414	1,432	982
1924	1,414	1,246	168
1925	3,432	1,470	1,962
1926	1,711	1,061	650
1927	527	267	260
1928	398	207	191
1929	175	0	175
1930	1,050	962	88
1931	502	502	0
1932	181	34	147
1934	14	14	0
1936	1,195	1,195	0
1937	1,142	1,142	0
1938	13	13	0
1939	283	283	0
1940	749	749	0
1941	1,123	1,123	0
1942	351	351	0
Total	32,007	15,210	16,797

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1883	203	1928				
1884	273	1894	52	1899		
1886	49	1887				
1889	82	1896	441	1911		
1892	63	1893				
1894	142	1932				

1½-in. Wrought-Iron and Steel Mains (contd.)

Retirements by Years (contd.)

Year Installed	Feet	Year	Feet	Year	Feet	Year
1895	8	1913	138	1926		
1896	480	1912				
1898	30	1912	1,355	1926	225	1932
1899	102	1914	74	1917	108	1933
1900	36	1904	192	1913	290	1922
	207	1928				
1901	467	1911				
1902	173	1911	179	1917		
1903	398	1913	133	1939		
1904	28	1913	125	1931	48	1934
	108	1937				
1906	192	1911	49	1917	40	1928
1907	163	1912				
1909	47	1917	88	1931		
1910	57	1917				
1911	111	1919	163	1925	217	1929
	373	1932	181	1941		
1913	251	1921	193	1924		
1917	3	1919	201	1924	13	1926
1917	27	1932				
1919	62	1936				
1920	892	1940				
1921	241	1925	200	1941		
1922	254	1924	135	1925	288	1926
	224	1929	365	1930	39	1931
	615	1932	19	1934	262	1940
1923	131	1925	67	1926	481	1932
	102	1940	137	1941	64	1942
1924	66	1927	102	1941		
1925	249	1925	127	1927	736	1929
	257	1931	543	1932	50	1941
1926	650	1939				
1927	260	1931				
1928	191	1929				
1929	175	1932				
1930	74	1932	14	1936		
1932	147	1937				

2-in. Wrought-Iron and Steel Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1875	373	0	373
1876	820	0	820
1877	5,368	0	5,368
1880	809	0	809
1881	137	0	137
1883	758	0	758
1884	555	0	555
1885	847	488	359
1886	3,545	0	3,545
1887	2,015	0	2,015
1888	3,838	0	3,838
1889	4,515	0	4,515
1890	865	0	865
1891	1,077	162	915
1892	1,742	212	1,530
1894	504	158	346
1895	2,432	213	2,219
1896	83	0	83
1897	1,688	0	1,688
1898	2,219	688	1,531
1899	407	61	346
1900	284	102	182
1902	507	467	40
1903	27	27	0
1904	16	16	0
1906	57	45	12
1907	12	0	12
1908	174	160	14
1909	1,285	81	1,204
1910	806	732	74
1911	1,090	348	742
1912	1,967	851	1,116
1914	76	0	76
1915	546	284	262
1916	2,347	753	1,594
1917	2,286	972	1,314
1919	1,854	0	1,854
1920	1,732	30	1,702
1921	8,297	3,071	5,226
1922	3,231	2,170	1,061
1923	7,344	3,194	4,150
1924	9,550	7,213	2,337
1925	7,230	5,654	1,576
1926	2,040	1,618	422
1927	4,666	3,459	1,207
1928	2,211	1,968	243
1929	1,425	1,425	0
1930	525	525	0
1931	805	805	0
1933	259	259	0
1934	326	326	0
1935	38	38	0
1936	532	532	0
1937	1,656	1,656	0
1938	1,001	640	361
1939	424	424	0
1940	424	424	0
1941	2,913	2,913	0
1942	2,518	2,518	0
Total	107,078	47,682	59,396

2-in. Wrought-Iron and Steel Mains (contd.)

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1875	13	1912	360	1915		
1876	85	1888	250	1896	204	1908
	281	1935				
1877	1,664	1892	586	1895	1,845	1896
	100	1908	68	1912	1,105	1913
1880	14	1890	220	1898	353	1905
	222	1929				
1881	137	1895				
1883	283	1894	475	1899		
1884	365	1914	190	1936		
1885	359	1899				
1886	969	1887	367	1898	323	1899
	1,431	1905	45	1919	410	1936
1887	212	1896	195	1905	354	1906
	708	1908	366	1916	180	1918
1888	602	1889	385	1890	635	1895
	1,393	1906	348	1908	475	1923
1889	1,115	1894	244	1895	544	1896
	307	1898	690	1908	283	1909
	1,004	1915	328	1924		
1890	469	1891	219	1915	84	1932
	93	1936				
1891	116	1896	429	1906	370	1930
1892	250	1906	246	1908	233	1912
	236	1915	350	1924	171	1927
	44	1932				
1894	201	1932	145	1933		
1895	456	1906	188	1912	120	1929
	200	1930	36	1936	1,219	1940
1896	83	1905				
1897	92	1905	14	1912	167	1913
	423	1929	697	1935	295	1938
1898	102	1906	93	1908	64	1912
	39	1914	30	1920	354	1924
	299	1925	144	1930	406	1932
1899	31	1935	315	1936		
1900	182	1901				
1902	30	1913	10	1934		

Year Installed	Feet	Year	Feet	Year	Feet	Year
1906	12	1912				
1907	12	1908				
1908	14	1919				
1909	137	1916	772	1926	295	193[illegible]
1910	74	1912				
1911	58	1912	9	1913	200	191[illegible]
	138	1921	33	1926	304	192[illegible]
1912	829	1915	14	1932	273	193[illegible]
1914	76	1926				
1915	10	1930	252	1942		
1916	186	1920	449	1930	166	193[illegible]
	793	1934				
1917	333	1920	7	1924	500	192[illegible]
	462	1930	12	1936		
1919	1,854	1921				
1920	90	1921	7	1927	1,035	193[illegible]
	463	1934	107	1939		
1921	253	1921	60	1922	60	192[illegible]
	389	1929	751	1930	570	193[illegible]
	698	1933	82	1934	1,049	193[illegible]
	990	1939	324	1940		
1922	340	1925	208	1926	45	193[illegible]
	38	1931	21	1934	405	193[illegible]
	4	1936				
1923	968	1926	12	1929	123	193[illegible]
	1,248	1932	1,441	1933	323	193[illegible]
	35	1939				
1924	558	1929	14	1931	112	193[illegible]
	218	1933	522	1934	81	193[illegible]
	832	1929				
1925	20	1933	1,071	1935	179	193[illegible]
	306	1939				
1926	422	1935				
1927	631	1929	349	1930	130	193[illegible]
	97	1941				
1928	31	1930	208	1935	4	193[illegible]
1938	361	1941				

2½-in. Wrought-Iron and Steel Mains

Year Installed	Feet Installed	In Service	Retired
1939	159	159	0
1942	0	0	0
Total	159	159	0

3-in. Wrought-Iron and Steel Mains

Year Installed	Feet Installed	In Service	Retired
1877	1,063	0	1,063
1885	90	0	90
1894	39	0	39
1895	810	0	810
1904	14	0	14
1942	0	0	0
Total	2,016	0	2,016

3-in. Wrought-Iron and Steel Mains (contd.)

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1877	1,063	1894				
1885	90	1909				
1894	39	1912				
1895	11	1898	362	1913	437	1920
1904	14	1915				

10-in. Steel Mains

Year	Feet		
Installed	Installed	In Service	Retired
1931	28	28	0
1942	0	0	0
Total	28	28	0

16-in. Steel Mains

Year	Feet		
Installed	Installed	In Service	Retired
1929	209	209	0
1937	44	44	0
1942	0	0	0
Total	253	253	0

18-in. Steel Mains

Year	Feet		
Installed	Installed	In Service	Retired
1940	12,803	12,803	0
1941	341	341	0
1942	0	0	0
Total	13,144	13,144	0

20-in. Steel Mains

Year	Feet		
Installed	Installed	In Service	Retired
1926	72	72	0
1936	53	53	0
1940	318	318	0
1942	0	0	0
Total	443	443	0

24-in. Steel Mains

Year	Feet		
Installed	Installed	In Service	Retired
1915	64	64	0
1929	7	7	0
1942	0	0	0
Total	71	71	0

30-in. Steel Mains

Year	Feet		
Installed	Installed	In Service	Retired
1909	2,163	2,163	0
1942	0	0	0
Total	2,163	2,163	0

36-in. Steel Mains

Year	Feet		
Installed	Installed	In Service	Retired
1910	318	318	0
1929	3,504	3,504	0
1942	0	0	0
Total	3,822	3,822	0

42-in. Steel Mains

Year	Feet		
Installed	Installed	In Service	Retired
1909	61,210	61,193	17
1926	504	504	0
1929	131	131	0
1931	85	85	0
1942	0	0	0
Total	61,930	61,913	17

Retirements by Years

Year Installed	Feet	Year
1909	17	1929

48-in. Steel Mains

Year	Feet		
Installed	Installed	In Service	Retired
1929	18,309	18,309	0
1942	0	0	0
Total	18,309	18,309	0

51-in. Steel Mains

Year Installed	Feet Installed	In Service	Retired
1929	13	13	0
1942	0	0	0
Total	13	13	0

54-in. Steel Mains

Year Installed	Feet Installed	In Service	Retired
1929	16,155	16,155	0
1942	0	0	0
Total	16,155	16,155	0

60-in. Steel Mains

Year Installed	Feet Installed	In Service	Retired
1932	71	71	0
1942	0	0	0
Total	71	71	0

66-in. Steel Mains

Year Installed	Feet Installed	In Service	Retired
1929	279	279	0
1942	0	0	0
Total	279	279	0

72-in. Steel Mains

Year Installed	Feet Installed	In Service	Retired
1929	23	23	0
1942	0	0	0
Total	23	23	0

¾-in. Copper Mains

Year Installed	Feet Installed	In Service	Retired
1940	60	60	0
1942	0	0	0
Total	60	60	0

1-in. Copper Mains

Year Installed	Feet Installed	In Service	Retired
1940	175	175	0
1941	79	79	0
1942	0	0	0
Total	254	254	0

1¼-in. Copper Mains

Year Installed	Feet Installed	In Service	Retired
1941	291	291	0
1942	0	0	0
Total	291	291	0

1½-in. Brass Mains

Year Installed	Feet Installed	In Service	Retired
1941	2	2	0
1942	0	0	0
Total	2	2	0

2-in. Brass and Copper Mains

Year Installed	Feet Installed	In Service	Retired
1940	578	578	0
1942	0	0	0
Total	578	578	0

2-in. Cement Mains

Year Installed	Feet Installed	In Service	Retired
1865	1,297	0	1,297
1866	313	0	313
1942	0	0	0
Total	1,610	0	1,610

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1865	230	1886	386	1890	361	1898
	320	1901				
1866	313	1887				

3-in. Cement Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1865	18,144	0	18,144
1866	11,290	0	11,290
1867	4,132	0	4,132
1868	3,077	0	3,077
1869	8,280	0	8,280
1870	4,375	0	4,375
1871	2,467	0	2,467
1942	0	0	0
Total	51,765	0	51,765

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1865	956	1884	268	1885	1,452	1886
	4,037	1887	8,908	1888	1,167	1889
	998	1890	358	1898		
1866	699	1884	45	1885	600	1886
	1,012	1887	707	1888	1,309	1890
	3,885	1891	730	1892	624	1895
	1,507	1898	172	1909		
1867	280	1884	345	1886	860	1887
	361	1888	709	1892	597	1895
	287	1899	644	1905	49	1908
1868	210	1885	226	1886	1,872	1887
	369	1890	400	1898		
1869	1,164	1885	48	1886	1,535	1888
	1,297	1890	1,065	1891	7	1892
	550	1894	1,510	1897	896	1898
	208	1909				
1870	700	1887	700	1888	150	1889
	2,082	1891	130	1893	206	1897
	407	1908				
1871	25	1888	422	1890	1,201	1892
	781	1897	38	1909		

4-in. Cement Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1865	859	0	859
1866	2,253	0	2,253
1867	324	0	324
1868	2,834	0	2,834
1869	1,688	0	1,688
1871	2,312	0	2,312
1873	2,321	0	2,321
1874	301	0	301
1875	5,680	0	5,680
1876	892	0	892
1942	0	0	0
Total	19,464	0	19,464

4-in. Cement Mains (contd.)

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1865	329	1884	70	1885	42	1886
	32	1890	386	1908		
1866	38	1885	1,109	1887	400	1888
	23	1903	683	1909		
1867	324	1899				
1868	52	1886	34	1890	964	1897
	658	1898	1,126	1904		
1869	48	1885	727	1889	913	1898
1871	46	1890	57	1897	24	1898
	1,204	1900	981	1909		
1873	50	1886	33	1888	370	1890
	1,527	1908	341	1909		
1874	52	1889	249	1906		
1875	23	1886	14	1890	28	1891
	210	1906	2,617	1908	227	1909
	127	1911	573	1913	711	1914
	1,150	1915				
1876	140	1904	369	1907	383	1914

6-in. Cement Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1865	7,215	0	7,215
1866	14,714	0	14,714
1867	4,593	0	4,593
1868	1,281	0	1,281
1869	577	0	577
1870	812	0	812
1871	1,300	0	1,300
1873	637	0	637
1874	344	0	344
1875	21,402	0	21,402
1876	577	0	577
1877	135	0	135
1879	150	0	150
1942	0	0	0
Total	53,737	0	53,737

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1865	1,332	1887	2,159	1891	1,684	1893
	38	1895	319	1899	1,481	1900
	202	1905				
1866	114	1885	5,596	1890	577	1891
	3,147	1893	460	1894	368	1897
	2,246	1898	1,857	1904	349	1909
1867	260	1887	463	1890	1,795	1897
	154	1899	1,921	1905		

6-in. Cement Mains (contd.)

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1868	232	1890	31	1891	90	1892
	11	1896	805	1898	112	1909
1869	577	1890				
1870	49	1889	45	1891	474	1893
	244	1896				
1871	1,300	1896				
1873	27	1891	42	1896	43	1897
	525	1909				
1874	30	1897	314	1908		
1875	25	1890	1,452	1906	12,646	1908
	412	1909	28	1910	995	1911
	1,373	1912	469	1913	1,416	1914
	2,586	1915				
1876	535	1891	42	1908		
1877	135	1908				
1879	150	1908				

8-in. Cement Mains

Year Installed	Feet: Installed	Feet: In Service	Feet: Retired
1864	6,076	0	6,076
1865	4,777	0	4,777
1866	1,217	0	1,217
1872	7,149	0	7,149
1873	1,742	0	1,742
1874	3,085	0	3,085
1875	7,014	0	7,014
1879	399	0	399
1942	0	0	0
Total	31,459	0	31,459

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1864	280	1885	2,530	1890	640	1891
	200	1892	1,512	1897	914	1909
1865	315	1885	1,796	1886	577	1887
	676	1891	527	1892	886	1909
1866	60	1885	1,157	1889		
1872	21	1891	828	1892	1,835	1901
	631	1907	3,834	1908		
1873	249	1897	1,493	1908		
1874	1,001	1908	47	1910	2,037	1914
1875	1,540	1907	1,264	1908	71	1910
	70	1911	94	1912	1,368	1913
	1,252	1914	1,355	1915		
1879	399	1908				

10-in. Cement Mains

Year Installed	Feet: Installed	Feet: In Service	Feet: Retired
1866	1,410	0	1,410
1871	1,075	0	1,075
1942	0	0	0
Total	2,485	0	2,485

Retirements by Years

Year Installed	Feet	Year
1866	1,410	1890
1871	1,075	1888

12-in. Cement Mains

Year Installed	Feet: Installed	Feet: In Service	Feet: Retired
1864	2,526	0	2,526
1865	3,462	0	3,462
1871	233	0	233
1874	10,420	0	10,420
1878	84	0	84
1882	356	0	356
1942	0	0	0
Total	17,081	0	17,081

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1864	2,526	1885				
1865	3,462	1892				
1871	233	1888				
1874	960	1888	28	1897	2,563	1907
	3,479	1908	2,690	1909	700	1914
1878	84	1908				
1882	356	1913				

16-in. Cement Mains

Year Installed	Feet: Installed	Feet: In Service	Feet: Retired
1874	14,660	0	14,660
1875	1,546	0	1,546
1942	0	0	0
Total	16,206	0	16,206

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1874	318	1890	2,930	1908	7,273	1909
	4,139	1910				
1875	1,136	1908	410	1909		

20-in. Cement Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1874	4,365	0	4,365
1942	0	0	0
Total	4,365	0	4,365

Retirements by Years

Year Installed	Feet	Year	Feet	Year
1874	265	1900	4,100	1909

24-in. Cement Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1874	52,675	19,460	33,215
1875	114	0	114
1942	0	0	0
Total	52,789	19,460	33,329

24-in. Cement Mains (contd.)

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1874	215	1885	2,814	1911	2,531	1912
	3,761	1913	13,989	1914	9,905	1936
1875	114	1908				

8-in. Asbestos-Cement Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1942	3,127	3,127	0
Total	3,127	3,127	0

10-in. Asbestos-Cement Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1936	1,232	1,232	0
1942	0	0	0
Total	1,232	1,232	0

Abstracts of Water Works Literature

Key: In the reference to the publication in which the abstracted article appears, **34**: 412 (Mar. '42) indicates volume 34, page 412, issue dated March 1942. If the publication is paged by the issue, **34**: 3: 56 (Mar. '42) indicates volume 34, number 3, page 56, issue dated March 1942. Initials following an abstract indicate reproduction, by permission, from periodicals, as follows: *B.H.—Bulletin of Hygiene (British); C.A.—Chemical Abstracts; P.H.E.A.—Public Health Engineering Abstracts; W.P.R.—Water Pollution Research (British); I.M.—Institute of Metals (British).*

IMPOUNDING RESERVOIRS

Basic Principles of the Design and Construction of Reservoirs and Tanks in Reinforced Concrete. G. P. Manning. Wtr. & Wtr. Eng. (Br.) **48**: 639 (Dec. '45). When reservoir sits on rock, solid chalk, deep bed of tight ballast or on well-driven piles, compression so small and usually so uniform as to be negligible. Heavy loading on clay always causes appreciable settlement; if reservoir *must* sit on clay, one can: (1) arrange that reservoir imposes no load on site, (2) arrange uniform settlement, (3) build series of small settlement-proof tanks, (4) use flexible steel tank, earth dam with flexible core, etc. Beds of tight sand good bearing if confined laterally. Full upward pressure of ground water must be allowed for on tank floor. Std. problem of restraint in circular tank well known, but all forms of constr. suffer more or less from secondary stresses. Of greatest importance to avoid designs where max. shrinkage tension, max. temp. stresses and max. structural stresses occur at same place and in same direction. Concrete kept continuously wet shows little or no shrinkage. Concrete kept permanently dry may shrink 0.04% in 2 yr. Shrinkage of wall top in open circular tank causes diminution of top diam. with "restraint" type moments in walls. Only in exceptional circumstances will contraction joints be required. Ideal way of building reservoir is: (A) use cement which gives off min. heat during setting; (B) provide complete form for whole tank, or for section between shrinkage-contraction joints if tank is cut into sections; (C) concrete whole tank in one continuous operation; (D) leave forms in place until concrete has cooled down and gained plenty of tensile strength, say 1 wk.; (E) protect and water concrete continuously for month. Tanks crack because of: (1) bad design—failure to appreciate possibility of settlement, shrinkage and temp. effects; (2) bad specifications—failure to appreciate vital need for workability in concrete mix; (3) bad constr.—failure to provide adequate form work and concrete plant, resulting in multiplicity of old-to-new constr. joints; (4) bad usage—filling cold tank quickly with hot effluent, boiler blowdown, etc. If steel starts to show after few years of service all loose concrete should be removed and cut back behind steel to get key. Surface should be patched with sand and cement using good non-shrink water-proofer, and then painted over with several coats of good bitumen or rubber-base paint. Asphalt or similar lining should cover faulty workmanship at constr. joints. Inst. of Civ. Engrs. Code of Practice imposes condition that steel stresses in flexure and shear shall be limited to 12,000 psi. and that calcd. stress on concrete in flexure shall not exceed 250 psi. Is writer to ignore code and repeat his designs that have stood test of usage, or scrap his 40 yr. experience in design and constr., involving community in seriously increased expenditure?—*H. E. Babbitt.*

The Protection and Decoration of Concrete. H. Courtney Bryson. Wtr. & Wtr. Eng. (Br.) **48**: 647 (Dec. '45). Engr. often overlooks fact that concrete is active, chem. substance; an alk. material. Chemically basic substances present in concrete slightly sol. in water and free to attack material in contact with surface. Concrete tanks cannot be used to store variety of chems. Concrete dams should not be used where water contg.

much carbon dioxide, or is otherwise acid. Property of concrete to exude alk. renders normal painting procedure on fresh concrete impossible, as alk. attacks oil and turns paint into sticky, non-drying soap. Many pigments, not fast to alk., discolored. Sol. salts in concrete likely to effloresce. Hydrostatic pressure sufficient to push off all but most tenacious of paint films, unless porous, when crystals grow through paint. Problem may be considered in two sections; decorative and protective. Ordinary water paint or distemper forms excellent temporary decoration, since it is alk. resistant. Distempers possess little resistance to weather; are not recommended. Chem. treatments usually applied to concrete to render salts in concrete harmless: (a) acid method or (b) fluosilicate method. Acid method consists of neutralizing free alk. on surface by means of acid. Fluosilicate method depends on conversion of alk. substances into insol. bodies by means of treatment with soln. of sol. fluosilicate. Unfortunately, resistance to chems. not only criterion that has to be applied to paints for concrete. Chem. inertness and poor adhesion nearly always go hand in hand. Paints for concrete generally composed of one or other of following: chlorinated rubber vinyl resin, cumarone (synthetic) resin, oil sol. (synthetic) phenol-formaldehyde resin, linseed stand oil, dehydrated castor oil and tung oil. Last difficult or impossible to obtain, and other oils may be used to replace it with some sacrifice of water resistance, alk. resistance, drying time or adhesion. Bitumen and so-called "white" bitumen admirable materials, considered solely as protection, since they are both completely alk.-proof and possess good adhesion. So-called synthetic paints may or may not be suitable for application to concrete. Where decoration only is concerned, treatment with distemper contg. wax emulsion, or with neutralizing fluid, recommended for concrete. Where protection against corrosive water and other liquids is object, then hard to beat 2 coats of varnish or paint made from cumarone resin and tung oil.—*H. E. Babbitt.*

The King Opens Ladybower Reservoir. Completion of Derwent Valley Water Board's 10-Year Scheme. ANON. Surveyor (Br.) **104**: 563 (Sept. 28, '45). Ladybower reservoir largest artificial reservoir formed by constr. of earthwork embankment in British Isles, if not Europe. Derwent Valley Act, 1899, authorized constr. of 6 impounding reservoirs. Of these, Ronksley, Howden, Derwent and Bamford were in Derwent Valley, and Hagglee and Ashopton in Ashop Valley. None constructed as originally planned, except Howden reservoir; present Derwent reservoir being modification of that originally planned. First installment of scheme consisted of Howden and Derwent reservoirs, aqueduct and filters. Howden and Derwent reservoirs similar, being formed by masonry dams, each 178′ thick at base, and having total capac. of 4100 mil.gal. (Imp.) By Derwent Valley Water Act of '20, board obtained powers to abandon reservoirs authorized by Act of 1899, and in their place to construct Ladybower Res., which, when completely filled, will have surface area of 504 acres, perimeter of 13 mi., and max. depth of 135′. Dam consists of earthwork embankment with clay core under which trench has been excavated and filled with concrete to prevent water in reservoir finding its way through ground beneath embankment. Surplus water, instead of flowing over crest of dam, will fall into two funnel-shaped overflows and be carried away under embankment through tunnels 15′ in diam. Length of embankment is 1250′, greatest thickness 665′, tapering to 17′ at top. Storage capac. is 6300 mil.gal. (Imp.). Estd. daily quant. of water available will be 53.666 mil.gal. (Imp.). By means of new filters capac. at Bamford has been increased to 12 to 24 mgd. (Imp.) and with chem. treatment acid and peaty water, often possessing fair deg. of turbidity, rendered slightly alk., clear, sparkling and colorless. Third line of pipes 48″ in diam. has been laid between Derwent Dam and Bamford filters, and all pipes between filters and Sawley have been duplicated.—*H. E. Babbitt.*

Economical Methods for the Maintenance of Impounding Reservoirs. K. J. WEIR, ET. AL. Ry. Eng. & Maint. **41**: 11: 1145 (Nov. 1945). About 10% of locomotive water supplies secured from reservoirs varying in capac. from 2 to 500 mil.gal. Excessive evapn. loss has caused trouble in some cases but this has been retarded by forestation to obstruct wind action. Absorption and seepage losses require careful consideration and prepn. of the reservoir site. Seepage through cavernous substrata has been remedied in some cases by applying layer of clay over entire area. Silting is greatest contributing factor to de-

creasing reservoir capac. and no inexpensive way found for removal. Prevention of erosion by checking sediment production at source considered important. Algae growth can be controlled by copper sulfate treatment. Proper maint. of dam and spillway necessary with rip-rap protection against wave wash. Live stock and burrowing animals should not be permitted around earth dams. Patrolling of watershed recommended.—*R. C. Bardwell.*

Water Engineer Under Water. DELWYN G. DAVIES. Wtr. & Wtr. Eng. (Br.) **48**: 509 (Sept. '45). Underwater operations among mysteries of civ. eng. that young engr. is not encouraged to learn. If engr. suspects faults in upstream face of dam he is faced with alternative of emptying reservoir or employing diver. Engr. at considerable advantage if able to inspect subaqueous works himself. Need for basic training in diving for members of water eng. profession is of paramount importance. First essential is to select young, fit and qualified engr., preferably under 30, capable of enduring considerable bodily and mental strain. Most engrs. regard diving as simple joy or very dangerous one. Pupil's first impressions important. Normal reactions vary considerably. On initial dive novice not comfortable until below water. Only those who have dived can appreciate work of professional diver.—*H. E. Babbitt.*

The Hollowell Reservoir Scheme for Northampton. With Special Reference to Movement of the Earth Dam. A. G. MCLELLAN. Wtr. & Wtr. Eng. (Br.) **48**: 7 (Jan. '45). In '35, prepns. made to proceed with revised edition of full scheme, comprising: (a) constr. of Hollowell Res.; (b) laying of 21" pipe from reservoir through existing tunnel to Ravensthorpe Works; and (c) filter plant at latter place. Constr. of sewers from 3 villages on gathering ground and sewage disposal works below site of reservoir also part of project. Hollowell dam impounds 460 mil.gal. (Imp.). Watershed area is 2500 acres. Avg. rainfall 26.5". Earth bank dam with following principal dimensions:

Length	1407′
Top water level	373′ above O.D.
Top bank level	378′ above O.D.
Max. ht. of dam	43′
Max. width of dam (toe to toe)	338′ (subsequently increased to 368′)

During earlier stages of trench excavation stream carried over trench in timber chute while diversion channel, tunnel and outlet channel being constructed. Turf and productive soil to total depth of 12" removed from area of seat of embankment. Puddle in core wall had top width of 7′ and battered down at 1 in 12. Top width of embankment is 15′ and finished with 8′ wide light metalled road. Overflow weir 100′ long curved on plan to radius of 160′. Overflow works calcd. to deal with flood of 1250 cfs. Disposal works designed to deal with sewage from 1200 persons. Separate stoneware pipe took storm water from largest of villages. Pipeline from reservoir to Ravensthorpe 3100 yd. long and of 21" diam. c-i. pipe. Total cost of work, exclusive of land, was £134,000. Plant chosen for new filters was of air-and-water-scoured rapid gravity type, consisting, in essence, of 4 concrete filtering tanks in open, and control app., etc., in brick bldg. surmounted by pure water tank to provide upwash for cleansing beds. Plant designed for max. output of 3.5 mgd. (Imp.) working at rate of 100 gal. (Imp.) per sq.ft. per hr. *Movement of Embankment:* Some time between Oct. 30 and Nov. 1, '37, surface of puddle core settled 16½" and moved 10" downstream, while points on downstream slopes moved 17¾" outwards. Movement continued during remaining period of constr. and records show that slight movement still taking place. Upstream face of dam had not moved to any appreciable extent. By end of Nov. total max. outward movement was 61" and total max. vertical settlement of puddle was 68". Borings showed that: (a) puddle had bent over like wand and developed bulge on downstream side; (b) no settlement in seat of dam in vicinity of cut-off trench; and (c) puddle and selected fill in good condition. Addnl. berm on lower downstream slope to resist movement and spread loading of embankment over greater area completed on Mar. 3, '38, by which time rate of puddle settlement decreased to ¼" in 24 hr. Then decided to shield area of soft clay from thrust of dam by heavy section, interlocking, steel sheet piles. Observations showed that piles were bent outward max. of 1½" in 67 days. Reservoir first overflowed on Apr. 1, '39. Factors which may reasonably be assumed to have contributed to movement can be summarized thus: (1) Presence of patch of soft spongy clay under old river bed; and (2) incidence of heavy rain following dry period during which making of embankment had been advanced to height when settlement might ordinarily be expected to take place. *Discussion. Ibid.* **48**: 111 (Mar. '45). WILLIAM C. KNILL:

History of scheme extended back to 1882 when Northampton Corp. seeking addnl. source of supply. Corp. decided in '11 to seek powers to construct reservoir. War broke out in '14 and constr. of reservoir could not proceed. In '21 Northampton suffered severe water shortage. Another shortage in '34. Corp. had no hesitation commencing Hollowell scheme. Many difficulties existed with old slow sand filters at Ravensthorpe, which had to be scraped every 2 to 3 days. Decided to centralize all filtration at Ravensthorpe and adopt primary and secondary filtration. E. SANDEMAN: (*Written communication.*) Embankment designed with unusually large base, 50% greater than ordinary practice would require on better foundation, because ground consisted of clay. J. KENNARD: Decided to over-reservoir watershed, to increase storage capac. to 460 mil.gal. (Imp.) which would increase yield from 0.835 mgd. (Imp.) to 1.145 mgd. (Imp.). Deducting compensation water safe reliable yield was 1,059,300 gpd. (Imp.). Survey of reservoir site had failed to disclose outcrop of rock bands. Safe to conclude that fairly thick impermeable carpet of blue liassic clay would prevent leakage of water from reservoir. Existence of area of bungum, or decomposed clay, under downstream seat of bank complete surprise. Much done in America in study of soil mechanics; in recent years Road Research Lab. had taken up matter in this country. When subject of soil mechanics mentioned, always some suspicious engrs. Proctor's theory states that there is certain optimum moisture content of soil at which compaction would produce max. density. If moisture increased beyond that point, partial flotation of soil grains set up and lower density results, so that shear strength of material is reduced. (Quoting Wentworth-Shields): "Recent researches in soil mechanics have been a Godsend to port engrs., particularly in solving their problems of heavy foundations and retaining walls." A. W. SKEMPTON: Little doubt that movement had occurred due to overstressing layer of soft clay described as "Bungum." Occurrence of soft clay in valleys should be expected and looked for. During last 10 yr. at least 7 recorded instances of banks having failed due to much same cause. Calcn. showed that addn. of new berm caused increase of about 16% in factor of safety. Sheet piling driven, increasing factor to about 1.09. Berm and piling together contributed 23% to stability. Dam judged to be close to failure and remedial measures accordingly designed with great care. Had bank at Hollowell been built by old-fashioned methods, material being moved by horses and carts, consolidation of bungum might have kept pace with increasing stresses imposed as work proceeded. C. F. LAPWORTH: If it had been found before work commenced that layer of bungum existed, it would have been possible to move center of dam. On basis of balancing forces tending to make dam slip and to prevent slip, Skempton had worked out avg. cohesion necessary to prevent sliding, and, assuming angle of 5°, it was something less than 1½ psi. Must have been some contributing factor other than layer of bungum which had led to slipping. DELWYN G. DAVIES: Natural tendency to criticize on ground that science of soil mechanics was not utilized. In '36 that science in its infancy. We are now beginning to know so much about soil mechanics that we are beginning to realize how little we know. To advance rational thesis for failure necessary to know properties of soil. Terms "bungum" and "rammel" of no value in assessment of problem. Important lesson taught is that prelim. exploration of clay sites and pre-examn. of materials of constr. vital to both design and stability. Eight test bore holes not sufficient for site ½ mi. long and 100 yd. wide. W. S. BOULTON: Exploratory work has obviously been painstaking and thorough, and evidence cited would seem to justify author's conclusions. Seems difficult to see how heavy rainfall from Oct. 23 to Oct. 31, when movement started, could have appreciably altered condition of bungum. Was heavy rain factor in starting movement only because its weight added to that of embankment filling? During period of heavy rainfall clay would absorb water directly from rainfall and would become more plastic and under pressure would tend to shear outwards and downwards. *Author's reply:* Skempton, Lapworth and Davies got at essence of problem when they talked of trial holes through seat of embankment. Considering that area occupied by bungum was only 3.5 or 4% of whole seat of embankment one could have put down many trial holes and still have missed bungum. Davies made important point when he referred to difficulty of consolidating selected filling. Water was used, under close supervision, and clay had to be chopped. Heaving due to frost was subject of controversy with contractors Placing of em-

bankment material had been stopped when there was heavy frost. L. H. Brown: No leakage whatsoever through embankment. Strainer, which it had been intended originally to install, would have helped primary filtration at certain times of year. Figures in paper for up-wash only. Cross-wash added 0.5%, so that total wash water was 1.5%. About twice yearly there is growth of *Asterionella* and *Fragilaria* and activated carbon good to use for that. C. A. Risbridger (*Written contribution*): Not at all certain that either of causes deduced by author main cause of trouble. Would appear reasonable to suppose that slip started before rain came. As to suggested cause of presence of soft spongy clay: (1) Observed to be *outward* movement of upstream slope. This indicates at least tendency to instability which might have developed in manner similar to downstream slopes had profiles been identical. (2) Plan shows bungum extended only 100′ laterally, yet slip extended over area between cross-sections 300 and 1000′. (3) If soft clay were important factor, not unreasonable to suppose that it would have been squeezed outwards *and* upwards, rather than to allow bank to slide over it. Selected filling appears to have been almost entirely clay. In its deposition considerable amt. of water had to be used. Clay very bad stabilizing agent in embankment. Selected material should be chosen solely on its merits as stabilizing agent to retain puddle core in its place. S. E. Hollingworth: Flowage of Lias clay under stress resulting from differential loading amply demonstrated in up-bulging of Lias in valleys of adjacent Ironstone Field. Two specific items in Hollowell section may be mentioned: (1) Apparent concn. of crumbling on west side of dam trench with beds in lowest part of valley but slightly disturbed. (2) Bearings of partial enveloping of thin gravel seam by overfolded rock band. Greater knowledge of constitution and distr. of "bungum" and of strength of individual layers in valley bottoms desirable. Whatever nature of "bungum" layer there may be some doubt, from apparently limited areal extent, whether its presence was sole cause of weakness of embankment foundation as whole. *Author's reply:* Author agrees that heavy rains could hardly have altered condition of "bungum." Extent to which care of selected filling fell short of being 100% successful might be measure of another contributory factor to produce slip.—*H. E. Babbitt.*

Sedimentation of Reservoirs. Special Rpts., U.S. Soil Conservation Service. L. C. Gottschalk. *Rpt. No. 1—Carnegie Lake, Princeton, N.J.* Lake created in channel of Millstone R. near Princeton by dam in '07. Investigations confined to tributary Stony Brook arm of lake of about 220-acre-ft. capac. Silting began immediately after constr. and by '22 about 62 acre-ft. of sediment, or 28% of original capac., developed. Between '37 and '39 (negligible amt. in '39) about 100 acre-ft. of sediment dredged out at cost of about $17,000. Capac. increased to 252 acre-ft. by excavating bottom in dredging operation. In July '39, 61 acre-ft. of recently deposited sediment, or 25% of total capac., found in lake after dredging. Assumed it will be reduced about half when consolidated. Watershed tributary to Stony Brook part of reservoir gently rolling to level, soil absorptive and several dams in streams. *Rpt. No. 5—Lochlaven and Prettyboy Reservoirs, Baltimore, Md.* Lochlaven original content, 65,800 acre-ft. (21,400 mil.gal.); drainage area, 303 sq.mi.; constructed in '14. Prettyboy original content, 60,300 acre-ft. (19,700 mil.gal.); constructed in '33. Both north of Baltimore and owned by city, and on Gunpowder Falls with Prettyboy upstream. Both long and narrow in gorgelike valleys although Lochlaven has several wide reaches. Largest area of watershed rolling upland with friable and easily washed residual soils. Over 50% cropland. Annual pptn. about 42″ with 55% in spring and summer. Capac.-watershed ratio of Prettyboy, 754 acre-ft. per sq.mi.; Lochlaven, 217 acre-ft. Avg. annual sediment produced per acre, 46.4 cu.ft. Capac. in Oct. '43: Lochlaven, 60,400 acre-ft.; Prettyboy, 59,800 acre-ft. Carl B. Brown: *Rpt. No. 6—Little Rock Reservoir, Los Angeles Co., Calif., near Palmdale.* Constructed in '24 and owned by Palmdale and Little Rock Irrigation Dists., supplying 2500 acres in Antelope Valley, west arm of Mojave Desert. Drainage area 68 sq.mi. rising 5000′ in its 15-mi. length. On north slope very steep San Gabriel Mts. Stream discharge erratic, highest instantaneous flood in recent times estd. at 17,000 sec.-ft. with annual flows as low as about 3000 acre-ft. No watershed fires since '24, no cultivation, scanty forest cover. Original length of reservoir, 6700′; present (Oct. '43) length, 5100′. Original surface area, 102 acres; present, 88. Original capac., 4200 acre-ft.; present, 3400. In '36 capac. was 4140 acre-ft. with total depreciation in capac. only 1.85%.

In June '38, after flood of that year, total depreciation, 13.49%, but large amt. of sediment left immediately upstream from reservoir coming in rapidly so that total depreciation Oct. '43, 19.28%. Original capac.-watershed ratio, 62 acre-ft.; present, 50 acre-ft.—*Harold Conkling.*

Reservoirs. ANON. Civ. Eng. (Br.) **39**: 1 (Jan. '44). Extracts from broadcasts made by H. H. Bennett, Chief, U.S. Soil Conservation Service, to Union of South Africa. Figures quoted by U.S. Dept. of Agric. show that surface soils of U.S. being eroded so rapidly that 21% of reservoirs will have useful life of less than 50 yr. Figures relative to silting of Dhukwan Res. in United Provinces (India) show capac., when originally measured in '07, as 56,244 acre-ft. When measured in '16 figure had reduced to 43,320 acre-ft. By '42 this figure had shrunk to 31,313 acre-ft. Flood water entering Lake Fyfe Res. in Bombay Deccan had silt content of 0.43 part per 1000, and 0.10 in non-flood period. Discharge at all times was 0.08 part. Only colloidal silt left dam. Figures eloquent of fate of this silt-trapping reservoir. While primary loser by soil erosion may be farmer, engr. is interested in phenomenon which destroys usefulness of his works.—*H. E. Babbitt.*

Impounding Works at La Rioja, Argentina. CARLOS A. VOLPI. Civ. Eng. (Br.) **39**: 148 (July '44). Avg. annual rainfall on catchment area from '25–'40 amts. to 235 mm. Discharge of water into Los Sauces Res. in same period is 491 l./sec., equivalent to 0.45 l./sec. per sq.km. Flow of La Rioja R. affected by great subterranean reservoir supplied by springs of Los Sauces in form of permanent discharge of 250 l./sec. all yr. round. From Dec. to Apr. in '30 to '36 some 14.5 cu. hectometers of flood water have reached dam of La Rioja Res. Capac. of reservoir will be diminished 10% in 7 yr. by sediment, giving useful life of 70 yr. Urgent search for water in La Rioja province has revealed considerable underground water. From 3 to 6% of rainfall absorbed; 97 to 94% lost by evapn. As result of heavy evapn. following losses recorded in '42:

Reservoir	*Flow, cu. hectometers*	*Losses due to evapn.* hm^3	*%*
La Rioja	9.5	1.2	12.6
Anzulon	9.7	6.2	64.0
San Felipe	10.1	6.7	66.0
Cruz Piedra	5.3	1.2	22.0
Rio Tercero	531.0	37.0	7.0

Impounding works at Los Sauces in La Rioja R. comprise rock rubble gravity dam 43 m. high, founded on alluvial stratum 20 m. thick; width of dam at center 112 m., upstream slope 1 : 1.1 and downstream 1 : 1.3 with total rubble of 272,000 cu.m. Hollow core wall of reinforced concrete provided along center line of dam. Normal capac. of reservoir is 21 million cu.m. Constr. camp built on works with houses, shops and dining rooms for workmen, schools for children, and special precautions for insuring health. Body of dam kept permanently wet to promote settlement assuming 40% voids in rubble fill. Downstream portion of dam has settled 30 cm. vertically, horizontal movement having produced deflection of core wall downwards in center of 110 mm. Temp. measurements of concrete taken by means of thermometers set in wall. Following facts established: (1) Increase of max. temp. due to setting of concrete has risen to about 15°C. above ambient temp. (2) Max. differences of temp. within mass of concrete have varied from 35° to 25° over period of 6 mo. Expansion joints in core wall provided with vertical cavity sealed with cement on coldest day of yr. and in one case with hot asphalt. Leaks over large area of core wall considerably reduced. Water from dam passes along bed of La Rioja valley for some 5000 m. to intake grille. Water conducted to main canal, then to 2 secondary canals. Works carried out by direct admin. in dist. little favored by nature where any proposed hydr. works must use last available drop of water.—*H. E. Babbitt.*

Remedial Works in Connection With the Waldershelf Slip—Broomhead Reservoir. LAURENCE BENDLOW. J. Inst. Civ. Engrs. (Br.) **6**: 95 (Apr. '44). Object is to describe remedial works successfully carried out in connection with landslip, known as Waldershelf slip, situated close to end of embankment and adjacent to overflow works of Broomhead Res. Unstable ground some 12 acres in extent. Fact that nearly 10 yr. have elapsed since completion of remedial works, without recurrence of trouble, deemed to establish their efficacy. First slip occurred in '24 during constr. of overflow works. Following remedial works constructed: (1) Constr. through slipped material of deep rubble wall drain to drain off water which might gain access to slip plane. (2) Removal of 400,000 cu.yd. of slipped material to lighten upper portion of slip. In April '30 further movement detected. Movement of second slip

only several inches. From remedial works for first slip there appeared, from standpoint of earth mechanics, no reason for instability. This gave rise to program of exploration to investigate causes of geol. origin. Trial holes sunk to depths ranging from 40′ to 90′. These indicated trough where slip plane led out to bed of ganister, and thereafter had rise in that direction. Lower trial holes indicate that bulk of slipped material consisted of violently disturbed sandstone, with inverted pockets of crushed shale. Water present in mass of sandstone, apparently having its source at higher levels. Following remedial measures decided upon: (a) Lighten upper part of slip by excavating about 165,000 cu.yd. of material. (b) Construct deep rubble wall drains into slope and extend drains into hillside. (c) Construct catchwater drains beyond margins of slip to prevent access of water to affected area. Throughout excavation of trenches no graet quant. of water encountered but occasional sudden runs indicated some slight pressure. However, after initial breakout they settled down to fairly const. flow. Observations on water level in bore holes made it clear that underground reservoir of water dammed up and maintd. at fairly const. level. When water in bore hole Y2 had been lowered 20′–25′ run of water from side of hole at about 730 (Ordinance Datum) clearly audible and visible, indicating that water being constantly fed by capac. of sandstone stratum at that level. Primary cause of first slip was that Waldershelf Knob situated directly over middle limb of monoclinal fold, anticlinal and sinclinal axes having mainly east and west course along north side of reservoir basin. Clearly first essential was to release water from shales below slip plane. Deep drains in progress pressed forward and work commenced on others. Excavation nearing completion when cracks higher up indicated that soft material forming slope had tendency to bulge. Scheme evolved for support without unduly adding weight by means of combination of rubble toe and system of reinforced concrete shoring whereby latter would take place of rubble blanketing and obviate stresses developing within soft material. Neither author nor engrs. under whom he served have knowledge of method of supporting unstable ground similar to shoring described.—*H. E. Babbitt.*

2,000,000-Gallon Reinforced Concrete Reservoir and Water Tower. Anon. Surveyor **102**: 387 (Sept. 17, '43). Rpt. of paper presented before meeting of local section of Inst. of Water Engrs. Author furnished details of erection of 1 mil.gal. (Imp.) capac., together with water tower of same capac. 37′6″ above it. Decided to use reinforced concrete, this being only suitable material. Almost all large elevated tanks have had circular shape in plan and none has had greater capac. than 750,000 gal. (Imp.). In gen., base slab of circular towers has consisted of dome and conical-shaped perimeter slab springing from circular arches which, in turn, supported by main columns carrying load to foundations. Columns rest on piers brought up from column bases at floor of reservoir to reservoir roof. Roof beams of rectangular type. Aggregates used in concrete were English Portland cement to B.S.S. std. In placing concrete, work divided into panels and concreted on "hit and miss" principle. Vertical joints of floor slabs in reservoir and tank arranged midway between rows of columns and each panel concreted continuously in one operation. Access to tank by means of concrete stairway leading on to roof of tank situated at two corners of structure. Screen walls at corner used to form stair well. On completion of work, tanks filled for testing and left for 14 days. Leaks observed, some of which disappeared after few days; others cut out and made good. Total cost of work, including all piping, £31,600.—*H. E. Babbitt.*